Build a Picoammeter, Start Experimenting (p.62) • Put a Multidimensional SBC to Work (p. 68)

CIRCUIT CELLAR

THE MAGAZINE FOR COMPUTER APPLICATIONS

#237 April 2010

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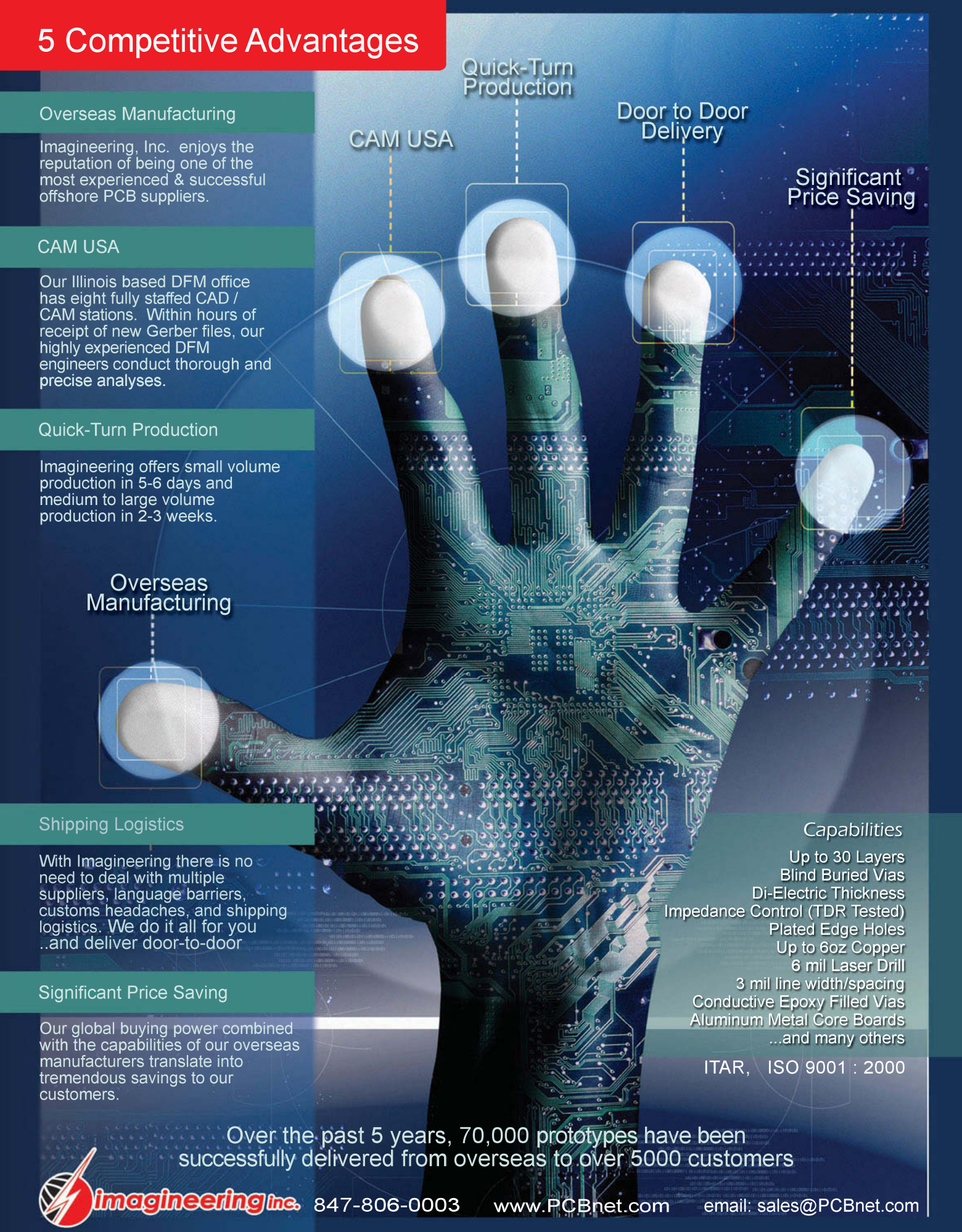

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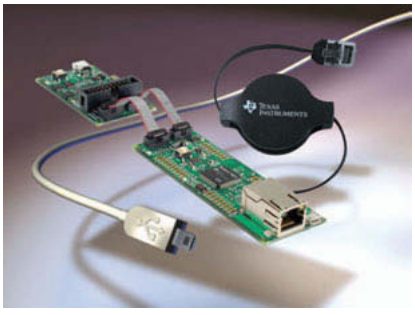

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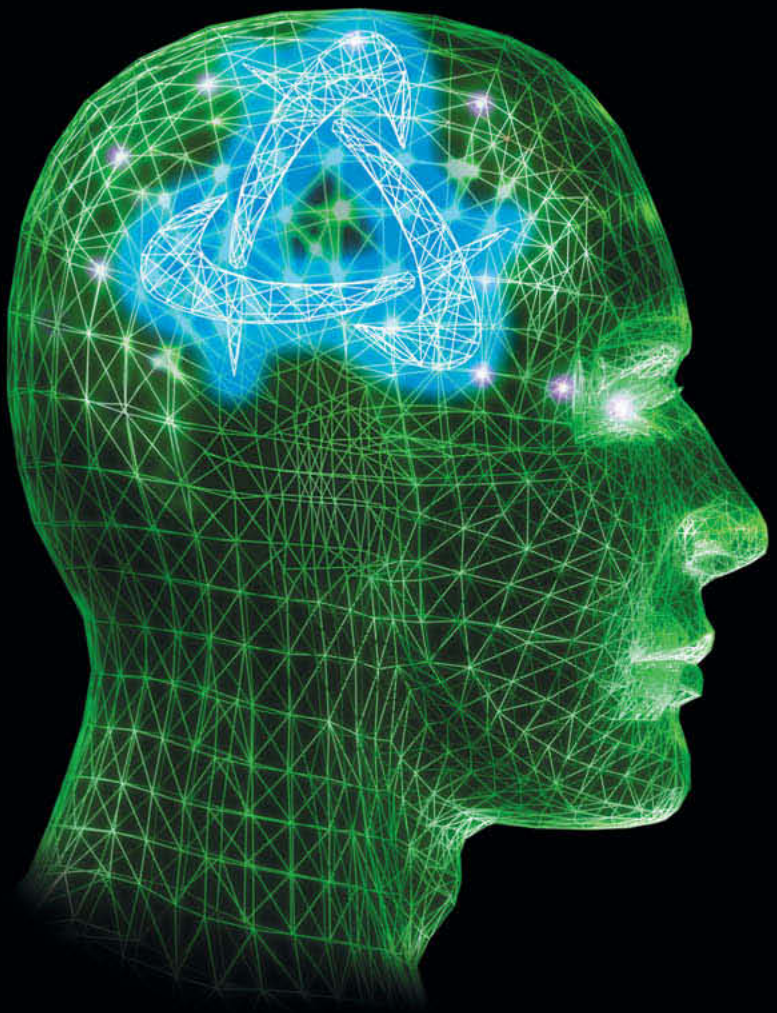

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TASK MANAGER

New Development

The *Circuit Cellar* staff has been looking forward to April for a while now—and not just because reaching this month on the calendar means we've made it through another long New England winter. April 2010 is special for another reason: color. We're proud to announce that this is the first full-color issue in the history of *Circuit Cellar*. That's right, we can run any photo, any diagram, or any advertisement in color.

Why is this a historic moment for *Circuit Cellar*? Well, it's obviously a huge perk to be able to see every image in all its brilliance. But the greater significance is that the act of converting to full color highlights the strength of the relationship between *Circuit Cellar* and *Elektor*. It's no coincidence that only a few months after joining forces with *Elektor* we've begun to pack more of an aesthetic punch on each page of the magazine, as well as to its cover.

One of the earliest editorial discussions between *Circuit Cellar* and *Elektor* colleagues was about immediate "deliverables" we could bring to readers. Our goals were to (a) enhance readers' overall *Circuit Cellar* experience and (b) signify the strength of the *Circuit Cellar-Elektor* union. Incorporating full-color pages was quickly agreed upon.

"Color is great," you say. "But what's the big picture?"

Well, like any new partnership, ours has been marked by enthusiastic conversations, exciting brainstorming sessions, and insightful idea swapping. The result of these exchanges has been the invigoration of all staffers with a sense of repurpose: Each month, we shall deliver fresh need-to-know information to engineers—and *more*. Our mission is to give you more content, more color, more topics, and more fluid connections between the magazine, its website, its authors, its advertisers, its contests, its code, and its other products.

This issue starts another season of innovative projects and novel embedded programs. Let's get started.

Kicking off the issue, Jeff Shoemaker tackles the topic of converter performance and presents tips for working with on-chip ADCs (p. 18). Turn to page 26 to learn how Jeff Bachiochi brought audio recording capabilities to an embedded design with a playback IC. On page 38 Peter Montgomery finishes his series on building a serial network hub with details about the software, hardware, and network packet transmission. In "Smart Control," Alexandre Guimaraes presents a useful DIY reflow soldering controller project (p. 46). Ed Nisley finishes his "Totally Featureless Clock" series on page 54 with a presentation of the overall design. On page 62, Robert Lacoste explains how to build a picoammeter for your workbench. Tom Cantrell completes the issue by presenting an exciting multidimensional SBC you'll find handy for future designs (p. 68).

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C. Abate

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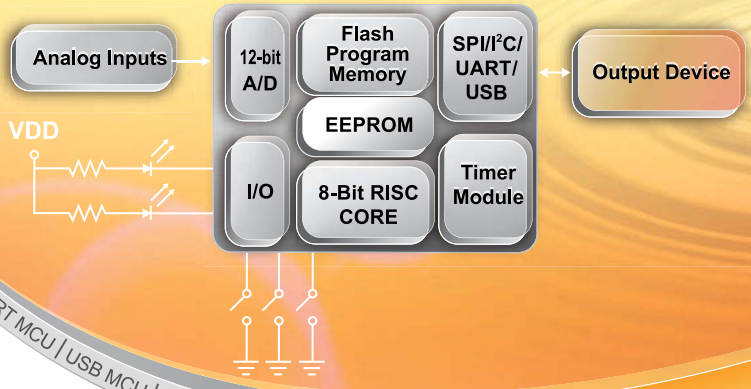

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HT66F20	2.2V~5.5V	400KHz~20Mhz or 32768Hz	1Kx14	64x8	32x8	18	4	V	V	2	12-bitx8	10-bit CTMx1 10-bit STMx1	V	4	2	SPI/I²C
HT66F30	2.2V~5.5V	400KHz~20Mhz or 32768Hz	2Kx14	96x8	64x8	22	4	V	V	2	12-bitx8	10-bit CTMx1 10-bit ETMx1	V	4	2	SPI/I²C
HT66FU30																UART
HT66FB30																USB
HT66F40	2.2V~5.5V	400KHz~20Mhz or 32768Hz	4Kx15	192x8	128x8	42	4	V	V	2	12-bitx8	10-bit CTMx1 10-bit ETMx1 16-bit STMx1	V	8	2	SPI/I²C
HT66FU40																UART
HT66FB40																USB
HT66F50	2.2V~5.5V	400KHz~20Mhz or 32768Hz	8Kx16	384x8	256x8	42	4	V	V	2	12-bitx8	10-bit CTMx2 10-bit ETMx1 16-bit STMx1	V	8	2	SPI/I²C
HT66FU50																UART
HT66FB50																USB
HT66F60	2.2V~5.5V	400KHz~20Mhz or 32768Hz	12Kx16	576x8	256x8	50	4	V	V	4	12-bitx12	10-bit CTMx2 10-bit ETMx1 16-bit STMx1	V	12	2	SPI/I²C
HT66FU60																UART
HT66FB60																USB

Part No.	VDD	System Clock	Program Memory	Data Memory	Data EEPROM	I/O	LCD SCOM	IRC	RTC	EXT. Interrupt	Timer Module	PFD	Stack	Comparator	Interface
HT68F20	2.2V~5.5V	400KHz~20Mhz or 32768Hz	1Kx14	64x8	32x8	18	4	V	V	2	10-bit CTMx1 10-bit STMx1	V	4	2	SPI/I²C
HT68F30	2.2V~5.5V	400KHz~20Mhz or 32768Hz	2Kx14	96x8	64x8	22	4	V	V	2	10-bit CTMx1 10-bit ETMx1	V	4	2	SPI/I²C
HT68FU30															UART
HT68FB30															USB
HT68F40	2.2V~5.5V	400KHz~20Mhz or 32768Hz	4Kx15	192x8	128x8	42	4	V	V	2	10-bit CTMx1 10-bit ETMx1 16-bit STMx1	V	8	2	SPI/I²C
HT68FU40															UART
HT68FB40															USB
HT68F50	2.2V~5.5V	400KHz~20Mhz or 32768Hz	8Kx16	384x8	256x8	42	4	V	V	2	10-bit CTMx2 10-bit ETMx1 16-bit STMx1	V	8	2	SPI/I²C
HT68FU50															UART
HT68FB50															USB
HT68F60	2.2V~5.5V	400KHz~20Mhz or 32768Hz	12Kx16	576x8	256x8	50	4	V	V	4	10-bit CTMx2 10-bit ETMx1 16-bit STMx1	V	12	2	SPI/I²C
HT68FU60															UART
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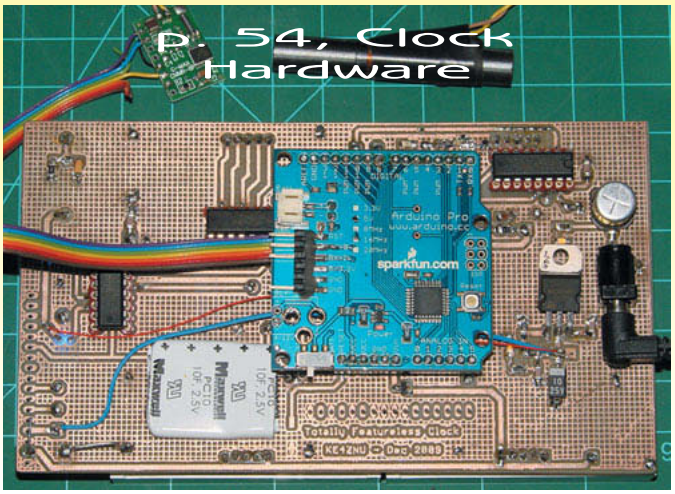

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SUITE SPEEDS APPLICATION DEVELOPMENT FOR AT91SAM3U MCUs

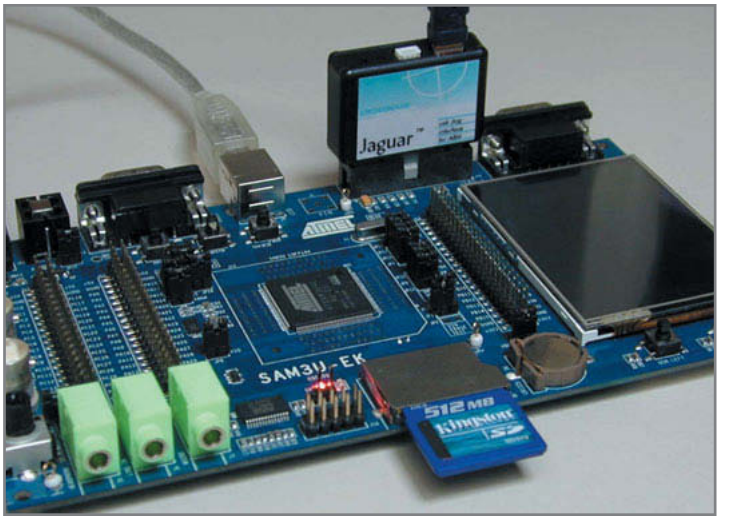
The **Crossware Development Suite for ARM** has been enhanced to make it compatible with Atmel's range of application examples available across its AT91SAM3U family of Cortex-M3-based flash microcontrollers. The enhanced suite allows developers using these MCUs to speed up application development and to rapidly experiment with the SAM3U-EK evaluation board.

Over 30 application examples are available demonstrating the use of the USB controller, the NAND flash controller, the SDIO/SDCard controller, the MMC controller, and various other on-chip peripherals. FAT filing systems, USB mass storage devices, LCD, mouse, and keyboard interfaces are all demonstrated. The application examples are imported into the environment in a structured way to make it easy for the developer to navigate through the source code and examine its operation.

The Workspace Creator uses the "make" file for the GNU versions of the Atmel examples to create a set of library projects and an application project. The appropriate command line options for the compiler, assembler, and linker are determined and included in the build instructions. The environment strings for the projects are determined and used to allow the compiler and assembler to access header files across directories and the linker to access the library files created by the library projects.

The Crossware ARM Development Suite runs on 32- and 64-bit Windows, features an advanced C/C++ compiler, libraries, wizards, simulator and debugger, and provides a complete and extremely user-friendly development environment for the ARM family of microprocessor cores.

Base package pricing starts at about **$445**.



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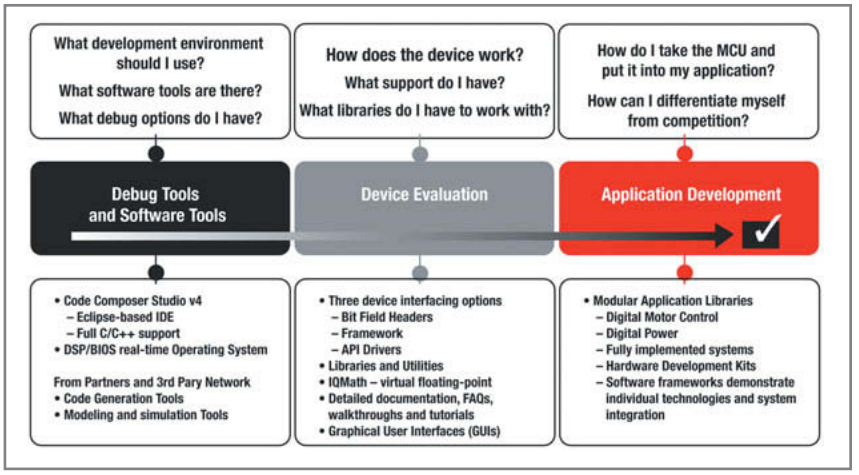
PACKAGE ACCELERATES DESIGN OF REAL-TIME CONTROL APPLICATIONS

Responding to the demand for more intuitive, easy-to-use software throughout every design stage, Texas Instruments has announced the **controlSUITE** software package for its TMS320C2000 microcontrollers. Going beyond the simple demonstrations common to free software portfolios, controlSUITE software includes libraries and examples that are full, open-source projects, serving as true development systems for applications such as motor control. Additionally, a new installer eliminates frustrations related to versioning and dependencies and gives developers access to the complete software offering in a centralized location.

Key features and benefits of controlSUITE software include: fundamental building blocks inside an intuitive system framework to simplify device start-up, configuration, tasking, and peripheral configuration; modular application level libraries and unique tools built into real-world systems and supported with open-source hardware examples; and the ability to reuse content across product lines and projects. A single controlSUITE portal allows developers to easily manage available software, collateral, and support. A new installer allows developers to select only the software components they require and gives the option for update notifications or automatic updates to eliminate version compatibility issues.


What development environment should I use?
What software tools are there?
What debug options do I have?
How does the device work?
What support do I have?
What libraries do I have to work with?
How do I take the MCU and put it into my application?
How can I differentiate myself from competition?
Debug Tools and Software Tools
Device Evaluation
Application Development
• Code Composer Studio v4
– Eclipse-based IDE
– Full C/C++ support
• DSP/BIOS real-time Operating System
From Partners and 3rd Pary Network
• Code Generation Tools
• Modeling and simulation Tools
• Three device interfacing options
– Bit Field Headers
– Framework
– API Drivers
• Libraries and Utilities
• IQMath – virtual floating-point
• Detailed documentation, FAQs, walkthroughs and tutorials
• Graphical User Interfaces (GUIs)
• Modular Application Libraries
– Digital Motor Control
– Digital Power
– Fully implemented systems
– Hardware Development Kits
– Software frameworks demonstrate individual technologies and system integration

A new High Voltage Motor Control and PFC Developer's Kit is the first to be based on controlSUITE software. The kit offers developers an open-source hardware and software platform to develop advanced motor control systems with digital power factor correction.

The free controlSUITE software is available at www.ti.com/cs_controlsuite-pr. The High Voltage Digital Motor Control & PFC Reference Design Kit costs **$599**.

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NEW PRODUCT NEWS

Edited by John Gorsky

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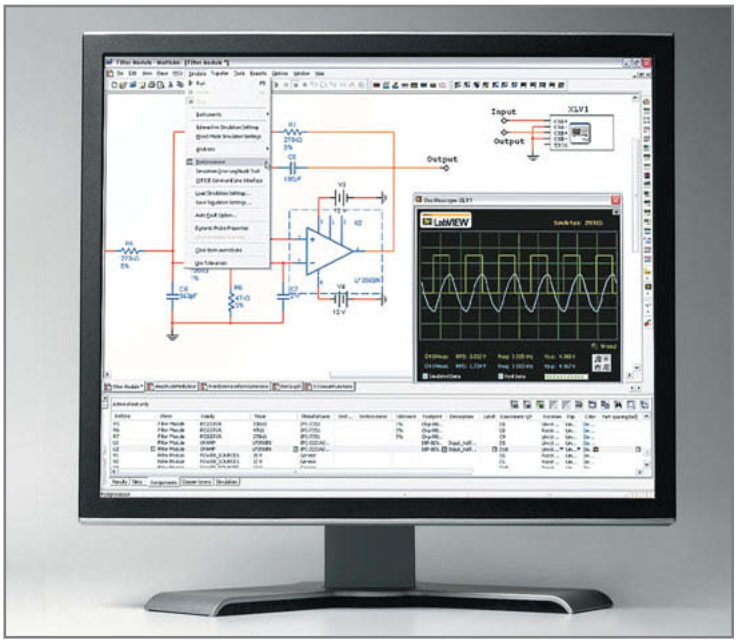
MULTISIM 11 SIMPLIFIES CIRCUIT SIMULATION

Multisim 11 is National Instruments's latest version of its circuit simulation software, with specialized editions for both hands-on learning and professional circuit design. The easy-to-use software delivers a graphical approach that abstracts the complexities of traditional circuit simulation, helping educators, students, and engineers employ advanced circuit analysis technology.

The academic edition of Multisim 11 incorporates specialized teaching features and is complemented by circuits, textbooks, and courseware. This integrated system helps educators engage students and reinforce circuit theory with an interactive, hands-on approach to investigating circuit behavior.

Multisim 11 Professional helps engineers optimize circuit designs, minimize errors, and reduce prototype iterations. When combined with the new Ultiboard 11 layout and routing software, Multisim provides engineers a cost-effective, end-to-end prototyping platform. Its integration with LabVIEW measurement software also helps engineers define custom analyses to improve design validation.



Key benefits of Multisim 11 Professional include the ability to better simulate with SPICE parser improvements, updated BSIM models, support for advanced parameters, and enhanced digital simulation accuracy. It also enables easier prototyping and ensures design synchronization and transparency with enhanced forward/backward annotation from the Multisim schematic to an Ultiboard layout. In addition, Multisim 11 offers improved design communication with on-page connectors and a new WYSIWYG net naming system.

The academic version costs **$499**. Multisim 11 Professional costs **$1,549**.

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USB ISOLATOR PROVIDES PERIPHERAL ISOLATION & HOST PROTECTION

Keterex, a manufacturer of mixed-signal integrated circuits and systems, has announced the availability of the **USB-150 Full-Speed USB Isolator**. The USB-150 electrically isolates a USB peripheral from its USB host while providing full, transparent USB connectivity.

The USB-150 is used in applications where the USB host and peripheral device may operate at different ground potentials, or where supply noise from the host must be eliminated. The USB-150 breaks ground loops and protects the host PC from electrical damage in these environments.

The USB-150 USB Isolator is rated for full-speed (12 Mbps) operation, and it is completely transparent to the host and peripheral. An isolated 5-V supply delivers up to 400 mA to the peripheral over the standard USB cable, enabling isolation of hub-powered devices. No software, device driver, or configuration is required. Any full-speed USB peripheral device can be electrically isolated from the host using the USB-150 and standard cables.

The USB-150 Full-Speed USB Isolator costs **$99**.

Keterex, Inc.
www.keterex.com

NPN

CMX-RTX AND CMX-TINY+ RTOS SUPPORT FOR EFM32 FAMILY

CMX Systems's **CMX-RTX** and **CMX-Tiny+** RTOSes are made for Energy Micro's ultra-low-energy 32-bit EFM32 Gecko microcontroller family based on the ARM Cortex-M3 Microcontroller Core.

The CMX-RTX RTOS supports most 8-, 16-, and 32-bit processors and DSPs, and it offers one of the smallest footprints, fastest context switch times, and lowest interrupt latency periods of any commercial RTOS available. RTOS functionality provided in CMX-RTX includes support for: tasks, messages, queues, system, events, memory, resource, semaphores, timers, interrupts, and optional kernel aware debugging. Flash requirements are approximately 1.5 KB minimum to 4.5 KB maximum.

The CMX-Tiny+ real-time multitasking operating system is a "lean-and-mean" kernel for those processors that have a small amount of RAM embedded on the processor's silicon (minimum of 512 bytes and higher.) This unique RTOS, based on a scaled-down version of the popular CMX-RTX, retains most of the power of the CMX-RTX, as well as the more frequently used functions. Flash requirements are approximately 1 KB minimum to 3 KB maximum.

The CMX-RTX and CMX-Tiny+ also feature full source code, no royalties, and free technical support and updates with every purchase.

The per-user license for the RTOSes is **$3,000** and includes free technical support and no royalty charge.

CMX Systems, Inc.
www.cmx.com

KIT MAKES IT EASY TO DEVELOP INDUCTIVE TOUCH-SENSING DESIGNS

The **PICDEM Inductive Touch Development Kit** (part # DM183027) makes it easy to develop inductive touch-sensing applications using standard 8-, 16-, or 32-bit PIC microcontrollers or 16-bit dsPIC digital signal controllers. The kit includes a fully developed inductive-touch board, complete with an embossed metal front panel, source code, schematics, and a diagnostic software tool that enables designers to evaluate their applications.

Inductive touch sensing's fundamental operating principles enable it to work through a front panel, such as plastic, stainless steel, or aluminum, providing a completely sealed user interface that works through gloves and on surfaces that contain liquids.

Major applications for inductive touch-sensing user interfaces include those in the appliance market because of the possibility of a stainless-steel front panel. Industrial applications are possible because of the technology's robustness. Automotive applications are possible because of the technology's sleek aesthetics and ability to reduce accidental touch triggers.

The kit is available for **$69.99**.

Microchip Technology, Inc.
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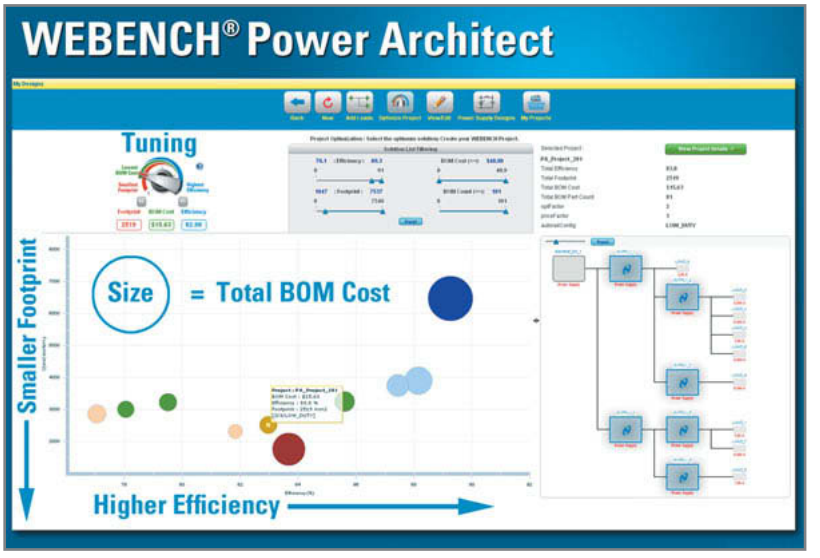
WEBENCH ACCELERATES DESIGN OF POWER SUPPLIES

The WEBENCH Designer tools have now been expanded with the introduction of **WEBENCH Power Architect**, the industry's first design tool that allows engineers to rapidly create, model, and implement multiple-output, high-performance DC-DC power supplies for an entire system. With WEBENCH Power Architect, system designers can instantly optimize multiple power supplies across several performance parameters including topology, intermediate voltage rails, footprint, efficiency, component count, and bill of materials cost.

WEBENCH Power Architect supports the new SIMPLE SWITCHER power modules. They provide highly integrated and easy-to-use solutions for power supplies requiring low part counts, small footprints, thermal resistance, and low EMI. Using a library of 21,000 components from 110 manufacturers, designers have a wide range of system alternatives for creating large-scale complex systems. The software can handle input voltages from 1 to 100 V, up to 20 system loads from 0.6 to 300 V, and per-load power requirements up to 300 W.

When engineers finish "dialing-in" their preferences for the footprint, the system BOM cost, and power efficiency, the graphical analysis capability instantly identifies major sources of power dissipation, cost, and footprint area. It allows the user to edit individual power supplies and loads to further model and optimize the overall system for thermal and electrical performance design goals.

When the design is complete, the tool generates a system summary report that includes schematics, a BOMs, and electrical operating values. Multiple international distributors provide pricing. The WEBENCH "Build It!" feature offers complete BOM prototype kits with overnight shipping. To view a video demonstration or begin a design with the WEBENCH Power Architect, go to www.national.com/powerarchitect.



National Semiconductor Corp.
www.national.com

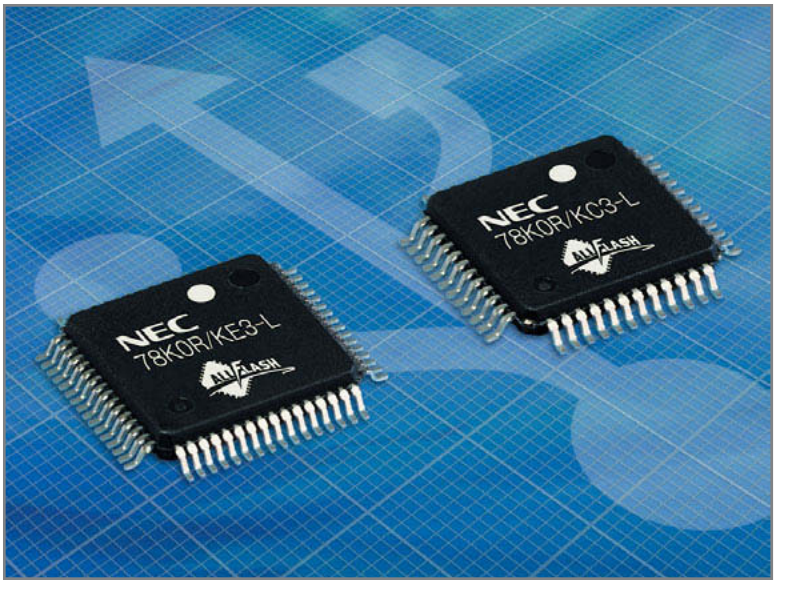
NEW 16-BIT MCUs WITH USB 2.0 FUNCTIONALITY

Twelve new 16-bit all-flash microcontrollers with built-in USB 2.0 functionality and industry-leading low-power consumption are now available. The new offering includes six 48-pin MCUs (**78K0R/KC3-L**) and six 64-pin MCUs (**78K0R/KE3-L**) with flash memory options ranging from 64 to 128 KB.

USB function drivers are available to handle device-specific functionality and other related tasks. Starter kits with USB evaluation boards, development environments, sample software, and documentation are also available. Certified by the USB Implementers Forum (USB-IF), the new devices offer manufacturers and consumers the assurance they will function in accordance with the specification and will interoperate with existing USB-enabled devices on the market today.

Achieving a low standby-power consumption of 1.2 µW, the MCUs also enable a low-active CPU-operation power consumption of 20 mW at 20 MHz. In addition to USB functionality, the products come with a mix of advanced peripherals, including 10-bit ADCs, 16-bit timers, a real-time clock, a watchdog timer, a 16-bit PWM, I^2C, and UARTs.

Suggested distribution resale pricing for 10,000-unit quantities ranges from **$3.40** to **$4.55**, depending on the memory size, package, and peripherals.



NEC Electronics Corp.
www.necel.com

ULTRA-COMPACT 20-W AC/DC POWER MODULE

The **RAC20-5B** is a highly efficient power module in the medium power range of up to 20 W. This ultra-compact converter measures only 52.4 mm × 27.2 mm × 23.5 mm (L × W × H). It is supplied in the same housing as the popular 10-W model, and it's also pin-compatible with the equally popular 5-W model.

The converters are designed for use on universal mains with input voltages of 90 to 264 VAC. They are available with output voltages of 3.3, 5, 12, 15, and 24 V. All the models attain an unusually low no-load consumption of under 500 mW. These not only meet the EU's "green power" policies for 2010, but also those planned for 2013.

Compared to its predecessor, the power density of the module has been increased by 120% to 0.6 W/cm³. Efficiency varies according to output voltage limits, reaching a peak of 86% at 24 V. In free air convection, the ambient temperature operating range of the converters is between –40° and 70°C. The RAC20-5B family is also fitted with an integrated class B filter. All models are isolated to 3,000 VDC minimum and exhibit an MTBF of 250,000 hours to MIL-HDBK-217F specifications.

The RAC20-5B costs **$29.76** in 1,000-piece quantities.

RECOM Electronic GmbH
www.recom-electronic.com

MICROCONTROLLERS FEATURE ON-CHIP DATA CONVERSION

The **ADuC7023** and **ADuC7122** are analog microcontrollers featuring data converters and other analog peripherals that combine to deliver a high level of programmability and small package size. Effective for digital diagnostics in optical transceivers and modules based on both fixed and tunable frequency lasers, the ADuC7023 and ADuC7122 precision analog microcontrollers use an ARM7 processor with up to 126 KB of flash memory to ensure the accurate control of optical drivers and diagnostics.

The ADuC7122 includes a 32-bit ARM7TDMI processor core operating at 41.78 MHz with 8 KB of on-chip SRAM and 128 KB of on-chip EEPROM memory with software-triggered in-circuit reprogrammability. While competing devices use PWMs and lower-performance ADCs to perform monitoring and control functions, the ADuC7122 microcontroller features a 14-channel, 12-bit, 1-Msps SAR ADC, 12 buffered 12-bit DACs, a programmable gain amplifier, and an on-chip temperature sensor. The ADuC7122 also features five timers, including a wake-up timer and watchdog timer, as well as two I²C interfaces, one SPI, one UART, and 32 GPIO signal pins that can be independently configured as inputs, outputs, or open drain.

For fixed-frequency optical transceivers in SFP, SFP+, XFP, and GPON, the ADuC7023 offers 8 KB of SRAM, 62 KB of flash/EEPROM memory, 19 general-purpose I/O pins, three general-purpose timers, and 16 programmable logic elements. Analog peripherals include a 12-channel, 12-bit, 1-MSPS ADC, a 16-bit, six-channel PWM, and four buffered 12-bit DACs.

The AduC7122 and the ADuC7023 cost **$8.90** and **$3.65**, respectively, in 1,000-piece quantities.

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USB DEVICE OFFERS DIGITAL PATTERN GENERATION AND SAMPLING

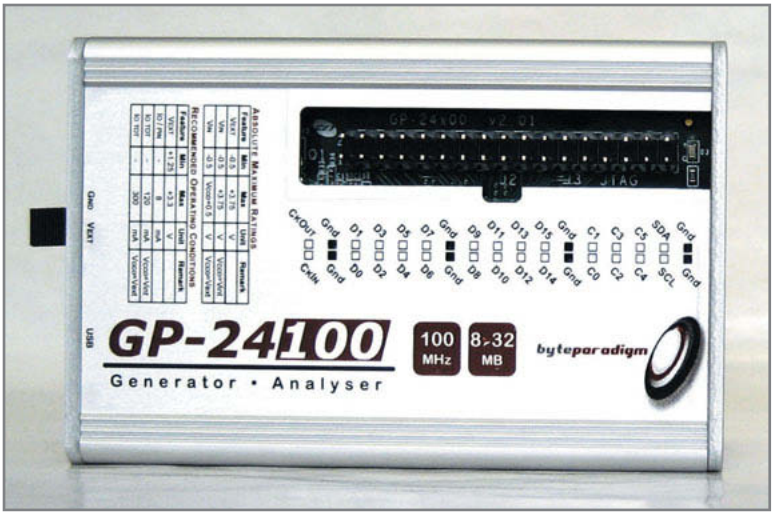
The **GP-24100** is a PC-controlled, USB 2.0 high-speed device featuring digital pattern generation and digital data-sampling capabilities. The GP-24100 can be used as a logic signal source early in the digital system development cycle to substitute for components that are not yet available. The device features 16 digital data lines running at up to 100 MHz either in or out, and a total memory of 8 MB. It is powered and interfaced through the USB connection.

In the past, troubleshooting and design verification looked like pure "measurement challenges," with logic analyzers and oscilloscopes as part of the solution. But these acquisition instruments have an important partner in the digital signal generator to form a complete stimulus-response solution for functional testing and debugging.

The GP-24100 is delivered with the 8PI Control Panel software suite, including Windows GUI, a TCL/tk interface, and access to C/C++ DLL. The C programming interface allows developing custom test programs from any C-compatible environment to automate and repeat specific tasks. GP-24100 also features: triggering, pattern looping and external I/O voltage selection from 1.8 to 3.3 V.

In addition to the standard ADWG (pattern generator) and logic analyzer mode of operation, the GP-24100 can be turned into a SPI master/analyzer and I²C master/analyzer with extra modes of operation.

GP-24100 is available now for approximately **$1,400** with standard options, software, and cables.



Byte Paradigm
www.byteparadigm.com

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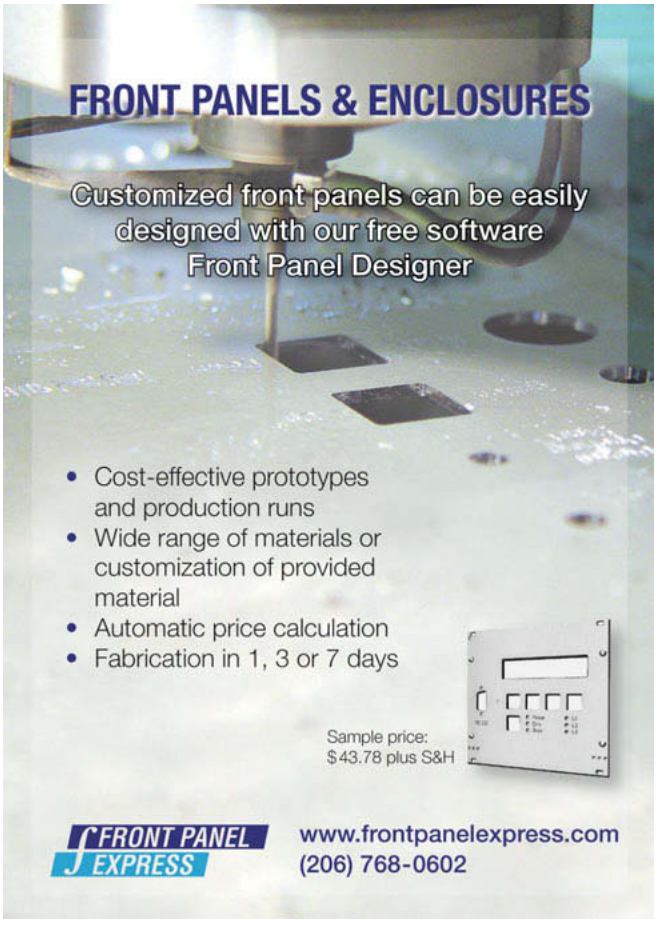
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SPI/I²C UART INTEGRATES AN OSCILLATOR AND SAVES SPACE

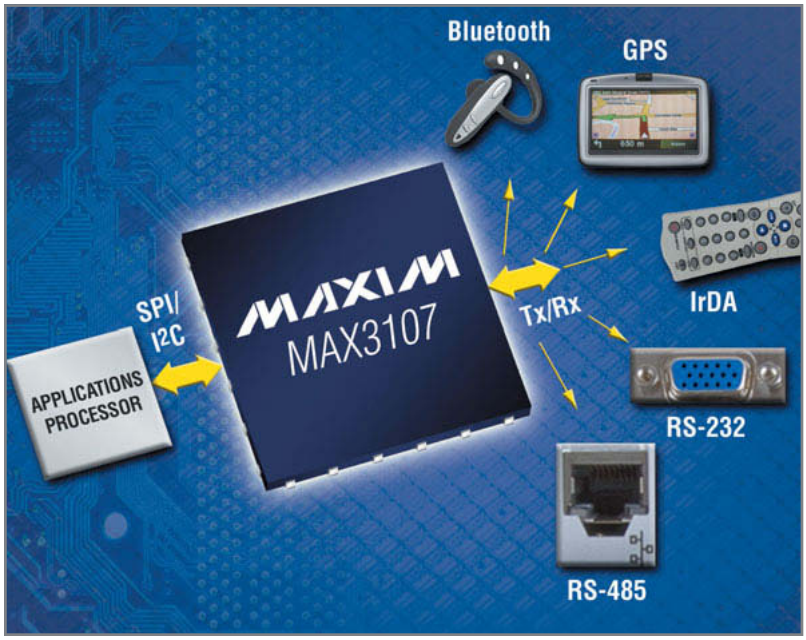
The **MAX3107** is the industry's lowest-power, fastest, and smallest serial UART to communicate over an SPI/I²C interface. The device's fast data rates (24 Mbps) and deep FIFO (128 words) allow additional buffering and thus relieve demand on the system's microcontroller. The MAX3107 also offers an industry first, an integrated oscillator that reduces BOM cost by an average of 20%.

The device's PLL, clock divider, prescaler, and fractional baud-rate generator allow the ultimate flexibility in high-resolution baud-rate programming. The baud rate is no longer dependent on the frequency of the reference clock, but it can be set independently to meet system needs.

The MAX3107 uses multiple operational modes to lower power consumption. The Sleep mode turns off all UART-related on-chip clocking, while the Shutdown mode turns off the chip completely. In Auto Sleep mode, the device automatically enters Sleep mode after a period of no activity on its I/O pins. The device automatically wakes up when activity is detected on any input pin.

The device operates from 2.35 to 3.6 V and is fully specified over the industrial –40° to 85°C temperature range. The MAX3107 costs **$3.25** (1,000-up, FOB, USA). An evaluation kit is available to speed designs.

Maxim Integrated Products
www.maxim-ic.com



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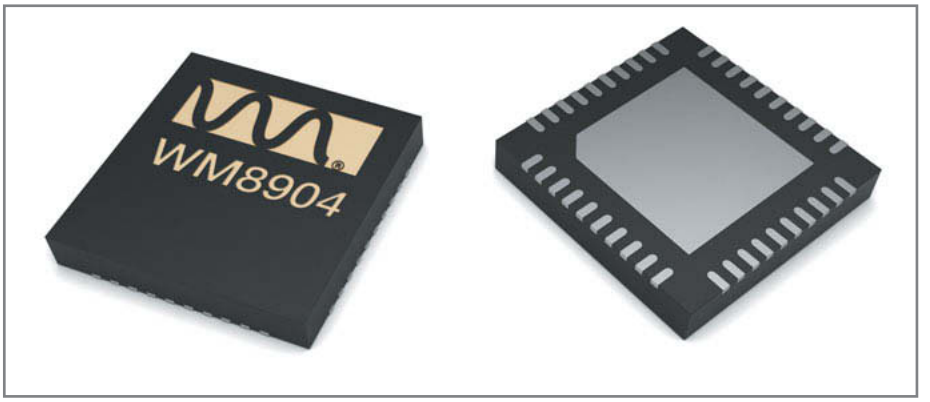
ULTRA-LOW-POWER AUDIO DEVICE

The **WM8904** is a leading ultra-low-power CODEC with Class W headphone and line drivers. It's designed to offer low-power consumption and significantly extend playback time in portable applications, such as media players, headsets, voice recorders, and multimedia phones.

Incorporated within the WM8904 is Wolfson's Class W amplifier technology, which intelligently tracks the actual music signal level and uses an adaptive dual drive charge pump to optimize power dissipation. The ground-referenced output also eliminates the need for large DC-blocking headphone capacitors, resulting in improved bass response, savings in PCB space, and the audio subsystem bill of materials. Also featured in the device is the innovative SmartDAC technology, a unique low-power DAC capacitor switching architecture, which enables DAC-to-headphone power consumption of just 4 mW and delivers up to 30 mW per channel into a headphone load. Audio performance is significantly enhanced with the integrated SilentSwitch technology, which extends its "pop and click" suppression capability by incorporating sophisticated clamp and sequencer circuitry.

The innovative RetuneTM Mobile parametric equalizer is a powerful feature that enables system designers to accurately customize the output signal path to optimize the performance of the speaker or other transducer. Line inputs—along with digital and analog microphone inputs—are all supported, with bypass paths to the class W headphone and line outputs.

The WM8904 is available for sampling now in a 32-lead 4 × 4 mm QFN, 36-ball CSP package. For 1,000-piece quantities, the WM8904 costs **$2.14**.



Wolfson Microelectronics plc
www.wolfsonmicro.com

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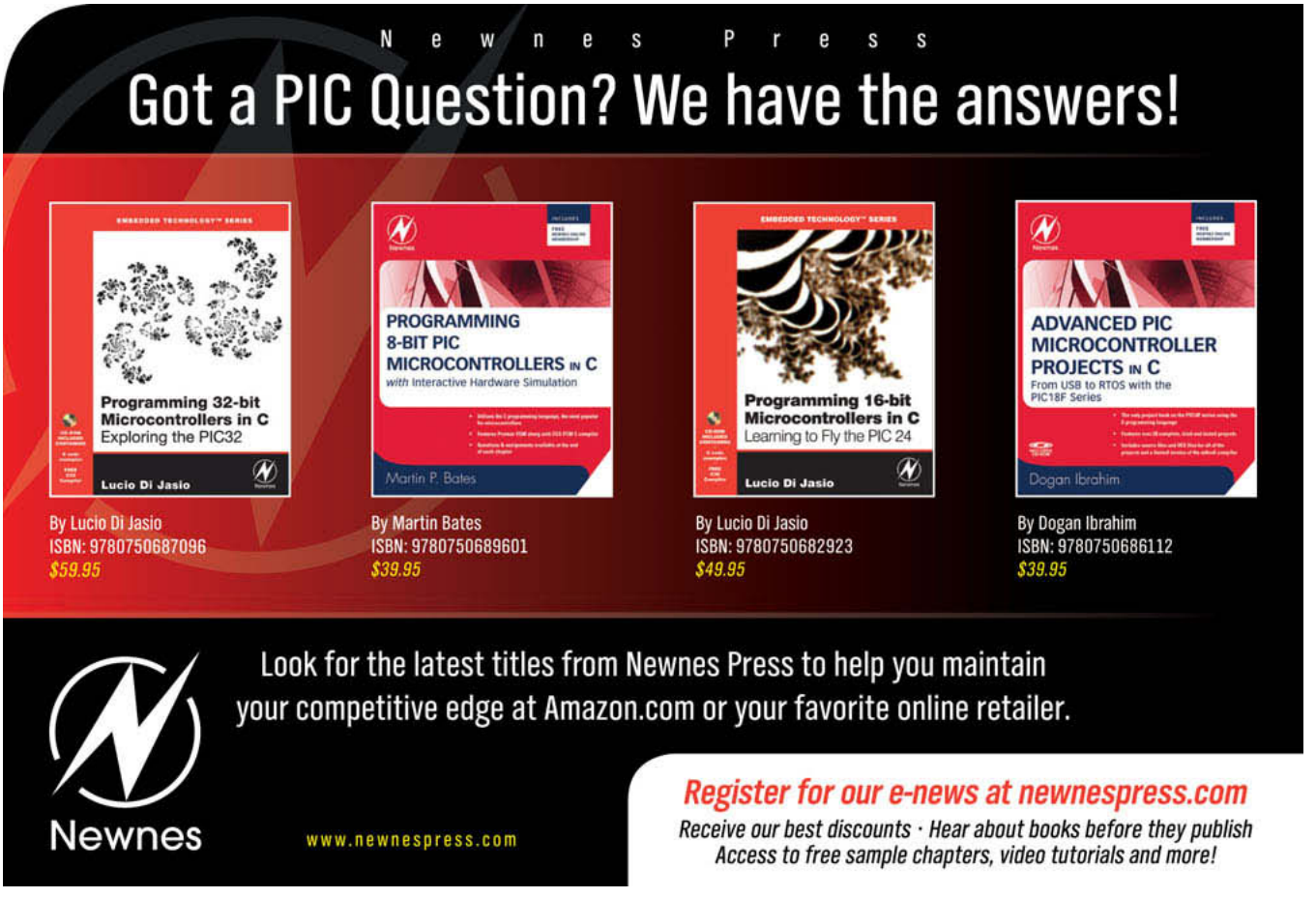
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Edited by David Tweed

Test Your EQ

ANSWERS for Issue 236

Answer 1—Symmetric encryption uses the same key for both encrypting and decrypting. The key must be shared between sender and recipient, and kept secret from everyone else. Some well-known examples of symmetric encryption are DES, IDEA, and AES.

Asymmetric encryption uses two complementary keys, one of which is used for encrypting and the other is used for decrypting. Sometimes the keys are interchangeable, in the sense that it doesn't matter which of the two keys you use for encrypting, you use the other one to decrypt.

Asymmetric encryption allows you to publish one of the keys publicly, which then allows anyone to send you a message that only you can read. This is known as public-key cryptography.

Public-key cryptography relies on math functions that are easy to work in one direction, but are exponentially difficult to work in the other. Some well-known examples of public-key encryption are the RSA algorithm (based on factoring), algorithms based on elliptic curves, and algorithms based on finite automata.

Answer 2—Public-key (asymmetric) cryptography enables several interesting functions for secure communication, including:

Authentication: A person can encrypt a message (or more typically, a hash of the message) with his private key, which can then be decoded with his public key. This is known as digital signature, and it allows anyone to verify that the message came from that person.

Integrity: A valid digital signature also verifies that a message wasn't altered after it was signed.

Nonrepudiation: By the same token, the person can't deny that the message came from him.

For example, these features can be combined to create a system for recording anonymous financial transactions, creating what is known as "digital cash."

Answer 3—In order to have a system that provides secure communications, you also need to pay attention to how keys are generated and distributed, and you have to pay attention to the protocols used to carry the data from one place to the other. Weaknesses in either of these areas can completely bypass a strong cryptosystem.

A lot of it comes down to human engineering—making sure the users of the system understand the nuances of what they should or should not be doing with the system.

Answer 4—While public-key cryptography provides one way to address the key-distribution problem, one of its major drawbacks is that it tends to be computationally very intensive to encrypt or decrypt a block of data, as compared to symmetric cryptography.

Therefore, most real cryptosystems (such as OpenPGP) use a hybrid system, in which symmetric cryptography is used to encrypt the message, but public-key cryptography is used to encrypt the random key—called the session key—used in the first step. This means that the computationally-intensive asymmetric algorithm is confined to a small chunk of data (typically 128 to 256 bits), while the bulk of the data uses the relatively efficient symmetric algorithm.

Contributed by David Tweed

What's your EQ?—The questions and answers are posted at www.circuitcellar.com/eq/

You may contact the quizmasters at eq@circuitcellar.com

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by Jeff Shoemaker

Converter Performance Management

Design Tips for Working with On-Chip ADCs

When creating an application that uses a microcontroller's integrated ADC, you need to know how all the parts (e.g., sensors) can affect the system's overall performance. This article includes design tips for getting optimal performance from an on-chip ADC.

Often, when designing embedded systems with analog-to-digital converters (ADCs) built into the microcontroller, a designer will spend a lot of time calculating the resolution needed for the system but neglect to spend any time understanding how other aspects can affect the analog-to-digital (A/D) performance. This article explores some of these other aspects and how they can influence (A/D) performance. It is not enough to just understand the specifications in the manufacturer's datasheet and how they affect performance. Sometimes, system parameters can be the limiting factor in performance, and not the ADC itself.

ADC ARCHITECTURES

The two most common ADC architectures found integrated into today's microcontrollers are Successive Approximation (SAR) and Sigma Delta converters. Figure 1 illustrates a block diagram of a successive approximation converter commonly found on modern-day microcontrollers. The basic premise behind the operation of this converter is that the analog signal being sampled is latched into a sample and hold circuit and fed into a comparator. The signal is compared to the output of an R2R ladder digital-to-analog converter (DAC).

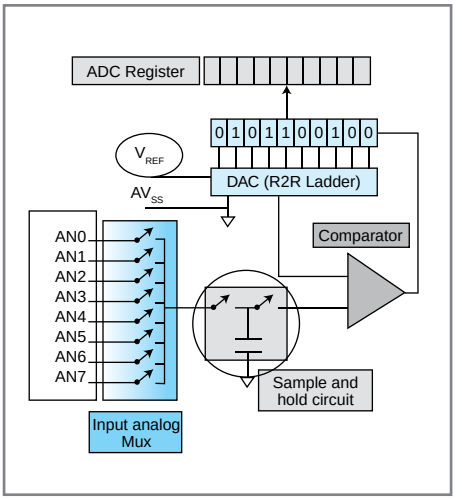

Figure 1—This is a SAR ADC.

The digital reading is constructed sequentially starting with the MSB and working down to the LSB by having the output of the DAC successively compared to the sampled signal until the operation is complete. Key advantages to this type of ADC are that it is relatively fast and it is easy to multiplex signals. However, high-resolution SAR ADCs can get very expensive due to the analog circuitry that can be difficult to manufacture with a digital process.

The Sigma Delta ADC is specifically designed for high resolution. As shown in Figure 2, the 4-V signal is fed into an error amplifier and the result is fed into an integrator. The integrator output, the slope of which is proportional to the input voltage, is compared to the reference voltage. The flip-flop generates the first bit (MSB). The advantage of this type of ADC is that it is mostly implemented in digital circuitry, making it easy to manufacture, and with the use of digital filtering, noise levels can be kept very low. This also ends up being a disadvantage if high-speed conversion rates are required due to the need for high-speed digital circuits in order to achieve this. The Sigma Delta architecture requires many samples

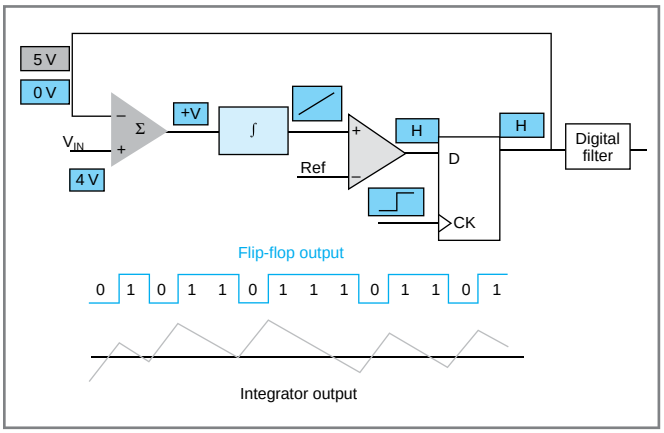

Figure 2—This is a Sigma-Delta ADC.

in order to construct the digital signal which can induce a phase delay that may be unacceptable to applications where minimizing phase delay is important.

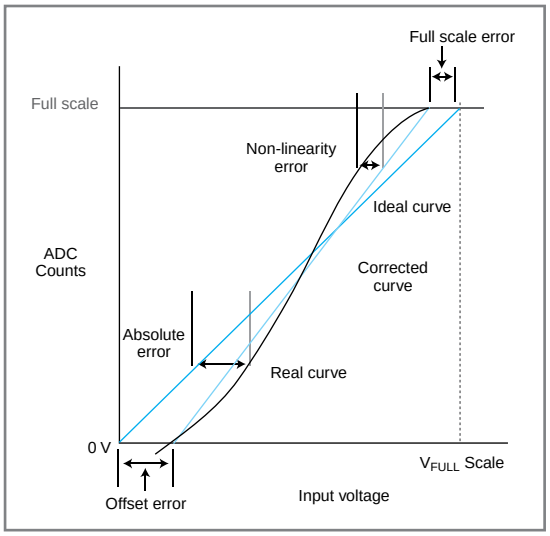

Figure 3—These are ADC error specifications.

Figure 3 shows an ideal transfer curve for an ADC. Here we have a straight line starting at 0 counts at 0 V extending up to full count and the highest voltage. The real transfer curve is going to deviate from this ideal curve. It will not be 0 counts at 0 V and will in fact have an offset known as the offset error. Conversely, when the voltage is full scale, the A/D counts may not be full scale. In that case, we have a full-scale error. When designing embedded systems that use ADCs, the manufacturer's datasheet will often denote the full-scale and offset error. These errors can typically be calibrated out with techniques that are well known. Note that the ideal curve is a linear, monotonically increasing function. The real curve is indeed monotonic but is not linear. The nonlinearity error becomes more difficult to calibrate, and doing so is often impractical.

SYSTEM-LEVEL POV

Now we will take a look at some things to consider from a system level point of view. First, it is important to consider the parameter being measured versus the actual resolution of the ADC. Of course, one often assumes that more resolution is always better, but you may not even need it. Let's consider a 10-bit ADC as an example. In this case, we can resolve up to 1,024 counts. If the measurement variable is temperature from 0 to 250°C, our example ADC can resolve down to 0.25 of a degree, or 0.1% accuracy. The point here is that you need to consider how much accuracy you really need, and over what dynamic range you really need it, and factor that against the actual resolution that the ADC is capable of. This requires understanding the sensor specifications and an understanding of how the system works.

Second, it is important to consider the step size that one bit can represent relative to the voltage range of the ADC. As another example, if you are using a 10-bit ADC with a 5-V reference, the smallest step size that you can resolve is 4.88 mV. But what if your sensor requires that you be able to resolve a 3-mV step change and also requires a full scale output of 5 V? There are a couple of design options in this case. One obvious approach would be to move to a 12-bit ADC. But you could also consider reducing the reference voltage. The 10-bit ADC, with a 2.5-V reference (a very common reference voltage), results in a 2.44-mV step change per bit with a full scale limit of 2.5 V.

Finally, there is a common misconception or interpretation of ±LSB error when reading the manufacturer's specification. For example, again referring to a 10-bit ADC, the manufacturer specifies a ±3-LSB error. It is common to interpret this to mean that the effective resolution is 7-bit resolution by dropping off the last three LSBs. This is not correct, however. What this type of specification actually means is that an ADC can be off by as many as three counts from the ideal count. So, for example, if a voltage is ideally 100 counts, it could read as 97 or 103 counts.

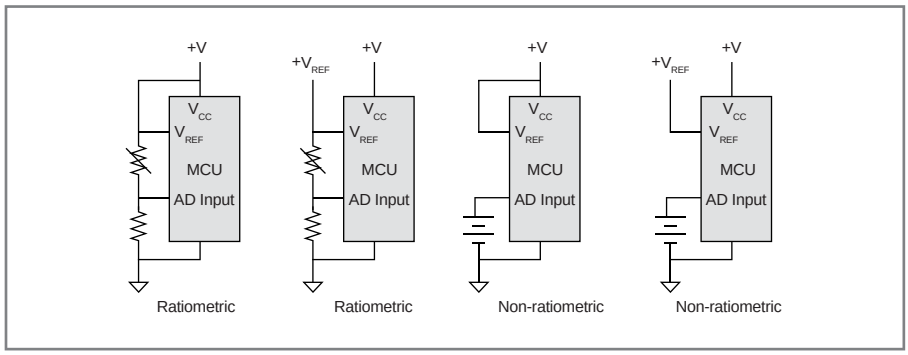

Figure 4—These are examples of ratiometric and non-ratiometric conversion connections.

RATIOMETRIC VS. NON-RATIOMETRIC

In addition to understanding the variable that is being measured, one needs to consider how to measure it to ensure that measurement error is minimized. Figure 4 shows some

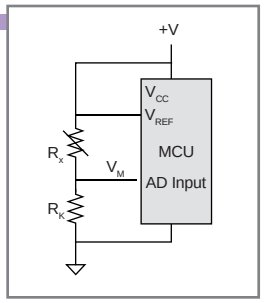

Figure 5—The ratiometric circuit for derivation of Equation 3.

examples of ADC connection configurations to illustrate the difference between ratiometric versus non-ratiometric conversions. By definition, ratiometric conversion means that the A/D input voltage is a fraction of the reference voltage. In the ratiometric cases in this diagram, the reference voltage can be connected to the microcontroller's VCC or to a separate reference voltage. The advantage of ratiometric conversion can be seen by observing what happens to the voltage equations. Refer to Figure 5:

$$V_M = V_{REF} \times \frac{R_K}{R_X + R_K} \quad [1]$$

$$\text{ADC reading} = \frac{V_M}{V_{REF}} \times \text{max ADC counts} \quad [2]$$

Substituting Equation 1 into Equation 2 yields:

$$\frac{\text{ADC reading}}{\text{Max counts}} = \frac{R_K}{R_X + R_K} \quad [3]$$

There are no dependencies on voltage in Equation 3. This is highly advantageous as voltage can vary with tolerance and temperature. The control variables are the resistor R_K and the resolution of the ADC. The result is that we now have a much more predictable and repeatable measurement.

Regardless of which method is used, there are sensing errors that must be taken into consideration. That is common to both ratiometric and non-ratiometric sensing. First, there is the error in the sensor itself. Little can be done to compensate in this case as this is intrinsic to the sensor unless the error can be reliably predicted. Second, there is the ADC error which has been discussed previously (i.e., offset error, full-scale error, etc.). In the case of ratiometric conversion, there is also divider error due to round off error and tolerance error in the resistor network. Tolerance error can be calibrated out. With non-ratiometric conversion, however, there is the error in the reference voltage that must be considered. A 4.096-V reference voltage is not always guaranteed to stay at that voltage at all times. This voltage can drift as a function of time and temperature and this typically cannot be calibrated out.

One must also consider the effects of source resistance (the resistance from the sensor) and how this can contribute to error in ADCs. Often the manufacturer's datasheet or hardware manual will

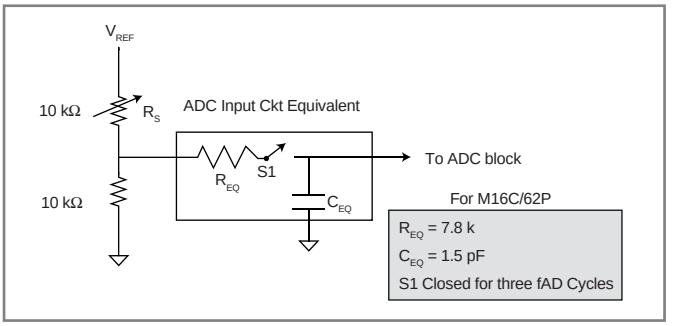

Figure 6—The RC time constant of the source resistance and the sampling capacitor can cause an error.

deal with this with their own formulaic approach. There is, however, an intuitive approach that I'll cover. Figure 6 shows an example which illustrates the ADC input equivalent circuit with the source resistance, R_S. The sampling switch, S1, is closed for 3 A/D conversion cycles. It is during that time in which the switch is closed that the capacitor, C_{EQ}, will be charged up to the input voltage. Note that the time constant will include the contribution from the capacitor, the input resistance, and the resistance of the source. Thus, the effect of the source resistance will affect the time that the capacitor charges and discharges, which can have an adverse effect on the accuracy. While this error can't be completely zeroed out, we can minimize it. Again assuming the microcontroller has a 10-bit ADC, let's say that we want an error to be much less than 0.1% (1/1024). With a 10-MHz ADC clock, the sample-and-hold capacitor charges for three cycles, which is a total time of 300 ns. So, let's target a 0.005% error, or 10 time constants to charge the capacitor. This requires that the RC time constant is not larger than 30 ns. Since C is 1.5 pF, the total resistance (source resistance plus the internal resistance) must not exceed 20 kΩ. Thus, the sensor's source resistance must be less than 12.2 kΩ (i.e., 20 – 7.8 kΩ).

So, what are the options for minimizing the effects of source resistance? The first thing that might come to mind is to actually decrease the source resistance. But this might not be practical if you are required to use a certain sensor or you are integrating your microcontroller to a legacy system. Another option may be to lower the sampling frequency. In many cases, the system may not need as high of a conversion rate. For example, if a 5-MHz sampling clock is used instead of the 10-MHz clock discussed previously, the time to charge the sample capacitor doubles and the allowable total resistance doubles. This results in a maximum source resistance of the sensor or 32.8 kΩ.

Yet another option that works well in many cases is to add a capacitor to the A/D input as

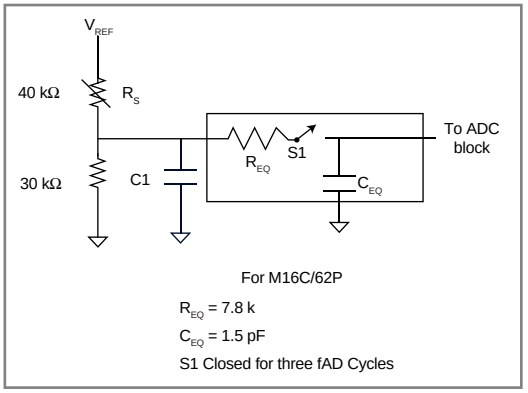

Figure 7—Adding a capacitor can be a simple way to mitigate the effects of source resistance error.

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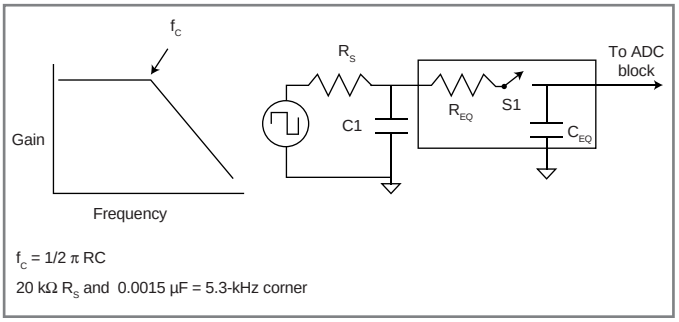

Figure 8—Adding a capacitor can also create a low-pass filter.

shown in Figure 7. This capacitor acts as a charge pump for the sampling capacitor. It is important to make sure that the charge capacitor is large enough that the contribution in total capacitance due to the internal capacitance of the ADC is very small. In this case, the change in voltage of the charge capacitor will be very small by the relationship Q = C × E. An important thing to remember is that when adding a capacitor to the circuit, you are creating a low-pass filter. Therefore, one needs to carefully consider where the corner frequency is set in the frequency spectrum, as indicated in Figure 8. A good rule of thumb is to set the corner frequency to be one decade higher than the highest periodic waveform that may be encountered.

SAMPLING FREQUENCY

This leads us to the next point in our discussion. Where do you set the sampling frequency? If you are just taking a measurement from a sensor to put on display (e.g., temperature), it is not that critical where the sampling rate is set.

Simply sampling the data and displaying it may not be a good idea since it is going to be noisy. To cut down the noise, try averaging it or oversampling by at least eight and then filtering. To get rid of the outliers, throw out the highest and lowest values in the array. You should also consider how you space those samples. In a slow-changing environment like temperature, the samples could be evenly spaced with fairly wide spacing to minimize noise. If you are trying to capture a signal that may change faster (e.g., a fan speed), you can still oversample, but you would typically have minimal time between the adjacent samples.

In the case of closed-loop control, the sampling rate becomes more critical. A sampling rate that is too slow will result in excessive delay in the system that can impede performance. There is no need to set the sampling rate faster than the system can control it. This is just wasting CPU resources. Instead, the sampling rate should be dictated by the system's dynamics and how fast the control system needs to respond to disturbances and yet perform adequately in its response time. Typically, the sampling rate is set several times faster than the highest bandwidth of the system. How many times faster is a trade-off between the control system performance, robustness considerations, and the limitations of the microcontroller CPU bandwidth and the ADC. It is also important to understand where the Nyquist frequency is when selecting the sampling rate to avoid aliasing.

Staying on the subject of delays in the system, it is also important to consider the effect of phase delay on the system due to the conversion rate. This is the difference between the time that the feedback parameter is actually measured and the time that it is available to be read by the control system. In an ADC, this is proportional to the conversion time. The longer the conversion time, the longer the phase delay. This can influence how well control system performance can be optimized and the robustness of the system to reject disturbances and maintain stability. Keep in mind that there are other factors that will contribute to this delay, such as how fast the result is read from the ADC, as might be the case in a multiple-input control system. For closed-loop control, if using an ADC for measuring feedback, it is important to make sure the ADC conversion rate is as fast as possible to minimize phase delay, and to have a thorough understanding of how the microcontroller reads the result into memory.

Often times in signal processing, we need to approximate an integral, such as when calculating the average voltage or average power. In some cases, a Riemann sum can be used for this approximation. When doing so, always remember that more samples are better. The Nyquist theorem states that when a periodic signal is sampled by more than twice the highest frequency component, sufficient information is available to reconstruct the signal. Note that this is sufficient to reconstruct the signal, but hat doesn't mean it will look pretty when it is done. Take a look at Figure 9, where the signal is sampled at twice the frequency but the integral approximation is not very accurate. Obviously, more samples will be needed for a more accurate representation. A designer can gain a better feel for how many samples are needed by performing the analysis ahead of time using a spreadsheet or Matlab.

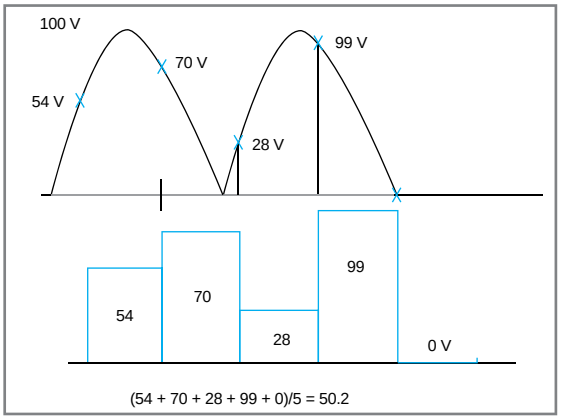

Figure 9—The effect of sampling at twice the base frequency poorly approximates the integral of the waveform.

SYSTEM PERFORMANCE

When designing systems that use a microcontroller's integrated ADC, it is important to understand how the system, the sensors, and other tangibles can affect the system's overall performance. It is essential to consider factors other than the resolution of the ADC. One must

consider the type of ADC and how it works and performs. But more importantly, one must consider the errors and how they can originate from internal and external sources. One must be aware that there are techniques available to mitigate some of these errors but not all of them, so the designer must have a thorough understanding of what the system can actually tolerate. It is important to consider the value that you are actually measuring and the range and accuracy that is required. In addition, it is necessary to have a solid understanding of where to set the sampling frequency and when it is critical. The sampling rate is not that critical when measuring a variable that is being put on a display, but it is extremely critical when making precise measurements or when performing closed-loop control.

Finally, be sure to consider the impact on the conversion rate and how this can affect closed-loop control. It is only with a well-rounded system-level approach that one can achieve optimal performance with on-chip ADCs.

Jeff Shoemaker is a Field Applications Engineer for Renesas Technology America. Previously, he spent a number of years as an embedded systems engineer working on embedded control system design in robotic and servo control systems. Jeff holds a Bachelor's degree in Electrical Engineering from the University of Minnesota and a Master's degree in Electrical and Computer Engineering from the University of Massachusetts, Amherst. You may contact him at jeffrey.shoemaker@renesas.com.

NEED-TO-KNOW INFO

Knowledge is power. In the computer applications industry, informed engineers and programmers don't just survive, they *thrive* and *excel*.

For more need-to-know information about topics covered in Jeff Shoemaker's Issue 237 article, the *Circuit Cellar* editorial staff highly recommends the following content:

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***Circuit Cellar* 185, 2005**

What happens when analog input frequency exceeds an ADC's ability to handle it? Ed presents a low-frequency, sampled-data circuit. Topics: ADC, DAC, Sampled Signals, Bandwidth

Go to: www.circuitcellar.com/magazine/185.html

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***Circuit Cellar* 170, 2004**

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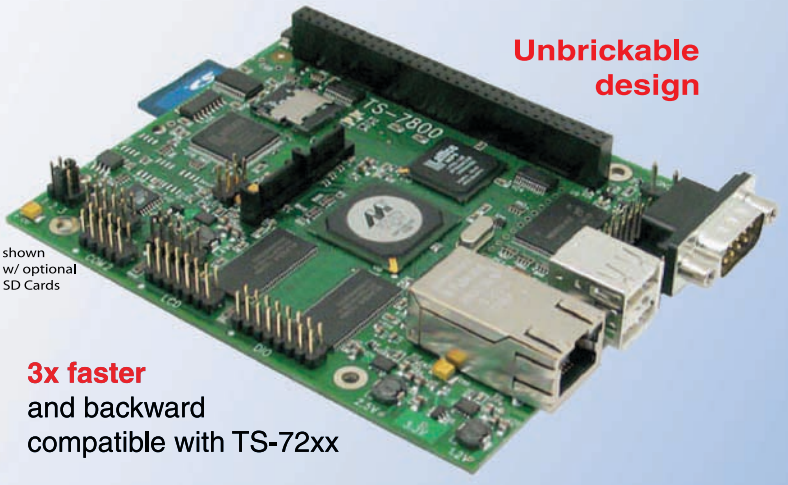

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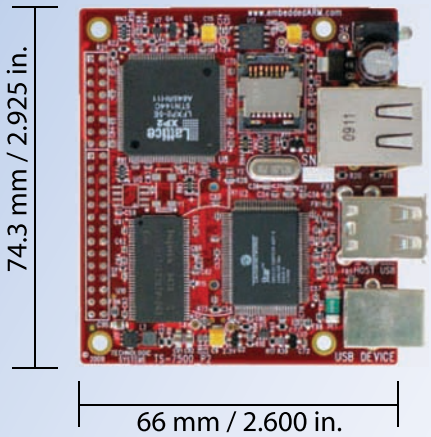

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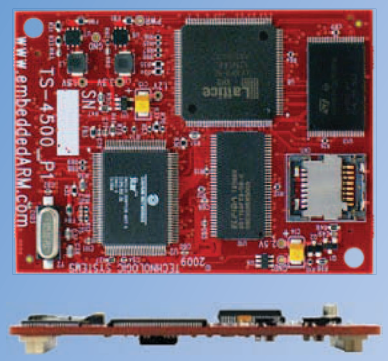

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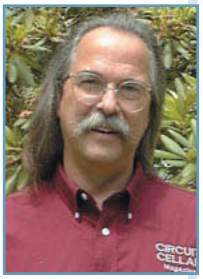


Read-Only Memories

Audio Applications with a Playback IC

If you want to bring useful audio recording capabilities to an embedded design, try working with a playback integrated circuit. It's easy once you resolve any memory issues associated with your design. This article details how to use a microcontroller to access a playback IC and associated EEPROM to play prerecorded audio files.

Let's start with a story. I'll begin with the first part of the story now. I'll wrap it up at the end of this article.

"Once upon a time, there was a king who was very sad. Whenever he was away, the children of the realm could not get to sleep since they were so used to hearing his voice read them into slumber land every night. So, the king called on Merlin for help. The wizard engineer had been experimenting with audio processing for some time, but had been unable to find suitable playback circuitry. But then one day Merlin was flipping through a new electronic parts catalog when he came upon a solution. Merlin used the royal credit card and had parts delivered by express owl."

A recent Hallmark commercial got me thinking about a past project. Over 30 years ago, I picked up an interesting music-playing birthday card at the Trenton Computer Fair. (Have you been to that fair?) I then devised a project around bit-banging a melody out of a small microcontroller. The user was responsible for choosing and programming the tune

Command	Opcode	Length	Type	Description
Reset	0000	8 Bits	Control	Cancels any pending operation and returns the device to its default configuration.
Stop	0001	8 Bits	Control	Halts the processing of any active audio command or phrase.
Set Duration	0010	16 Bits	Control	Specifies the length of time the tone generator plays tones in response to Play Tone commands.
Play Tone	XX11	16 Bits	Audio	Instructs the tone generator to synthesize a tone at the specified frequency.
Mute	0100	8 Bits	Control	Disables the speaker driver.
Unmute	0101	8 Bits	Control	Enables the speaker driver.
Play Phrase	0110	16 Bits	Audio	Retrieves and processes a phrase from external memory.
Set Volume	1000	8 Bits	Control	Sets the volume level of the output.
Set Outputs	1001	8 Bits	Control	Sets the state of the two general-purpose output pins.
Play ADPCM	1010	16 Bits	Audio	Sends 4-bit IMA ADPCM data to the audio processor.
Set Clock	1100	8 Bits	Control	Enables/disables the clock output (CLKOUT) and selects frequency.
—	1101	8 Bits	Control	Reserved.
Play PCM	1110	16 Bits	Audio	Sends 12-bit PCM data to the audio processor.

Table 1—These are the KX1400's commands. Most of the commands recognized by the KX1400 can be placed in an external EEPROM. These provide a simple yet powerful repertoire of control over the audio IC. An internal tone generator can provide musical output note by note, or prerecorded audio files can be played. Attaching a microcontroller adds a potential for user interaction.

out of frequencies and pauses. This project produced copious amounts of feedback. Everyone was looking for more than just a programmed sequence of beeps and boops. It wasn't in the cards at the time.

The first advance toward nirvana came with solid-state recording devices. Memory issues restrained these to a choice of high-quality/short-duration or lousy-quality/long duration. While this is subjective, you don't get something for nothing. File size is a problem. Just look at some of your MP3 music files.

Let me introduce you to the Keterex KX1400, which is an inexpensive playback circuit with a number of useful options. It can operate as a stand-alone device or as an MCU peripheral. In addition, the KX1400 has a built-in tone generator and a class-D speaker driver requiring no external low-pass filter. It comes as a 20-pin SOIC or 24-pin QFN part.

STANDING ALONE

As a playback device, the KX1400 gets its instructions by fetching data sequentially from an external EEPROM device. The instructions are listed in Table 1. Note that if the first command is to play an audio file, the remaining data in the EEPROM might consist entirely of data supporting one of three formats. The first is similar to my original project that produced tones to play out the melody of a favorite song. Each tone or rest (lack of tone) is accompanied by a duration that indicates how long the note (or rest) is held. The tone data is a 14-bit frequency index (0–16383) that corresponds to the frequency using the following formula: Frequency = FI/4.096. The frequency index needed to produce the tone equal to A (440) would be 1,802 (i.e., FI = 440 × 4.096). The duration data is simply a 12-bit number (0–4095) equal to the duration in milliseconds. Note that "0" is a special case that produces a continuous tone until a new command is received.

The remaining two formats are cause for jubilation. Anyone familiar with audio formats will recognize pulse code modulation (PCM) and ADPCM as audio formats that have been around for years. PCM files hold a sequential table of audio samples taken at a specific rate. Common sampling rates are at 8, 11, 22, or 44 kHz. Common sample data consists of 8- to 16-bit values. Obviously, the higher the sampling rate and the more resolution for each sample, the better the potential playback fidelity. As a point of comparison, the highest fidelity here would be 16-bit data at a 44-kHz rate consisting of a file size of 88,000 bytes per second of audio. A PCM file at the lower-quality end would consist of 8-bit data at an 8-kHz rate or a file size of 8,000 bytes per second. The KX1400's "Play PCM" command supports 12-bit data (squeezed into each 16-bit Play PCM command) and regurgitated at an 8-kHz rate.

Adaptive delta pulse code modulation (ADPCM) is a compression method for taking a 16-bit, 8-kHz PCM file and squeezing it into a much smaller size. The compressed 4-bit data fits into each 8-bit "Play ADPCM" command and thus effectively halves the storage space requirements. The ADPCM data must be uncompressed by the KX1400 as it is processed without compromising the 8-kHz playback rate.

UMBILICAL CORD

As you might expect, getting an audio data file through an SPI connection requires a rapid transfer clock. The minimum SPI clock speed for EEPROMs used here is 4 MHz. You can find many manufacturers that have been producing compatible

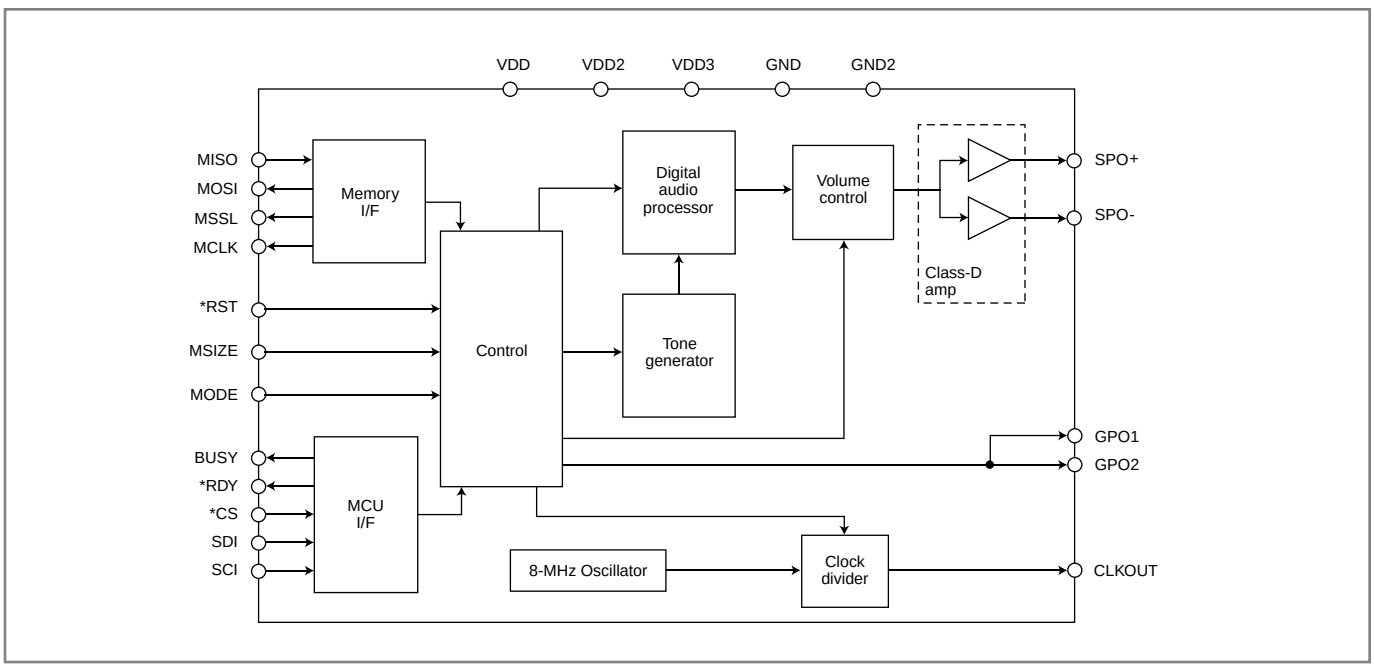


Figure 1—Two SPIs allow the KX1400 to retrieve data from an external EEPROM while receiving commands from an optional microcontroller. An internal tone generator and PCM/ADPCM decoder provide audio sources for the class-D speaker driver.

EEPROM 24-bit Address	Value	Command
0x0FFFFF	0x01	Phrase 0 - Stop
0x0FFFFE	0x04	Phrase 0 - Mute
0x0FFFFD	0x??	
0x0FFFFC	0x?E	Phrase 0 - Play PCM
……..		
0x000007	0x??	
0x000006	0x?E	Phrase 0 - Play PCM
0x000005	0x??	
0x000004	0x?E	Phrase 0 - Play PCM
0x000003	0x05	Phrase 0 - Unmute
0x000002	0x00	
0x000001	0x00	
0x000000	0x03	Vector for phrase 0

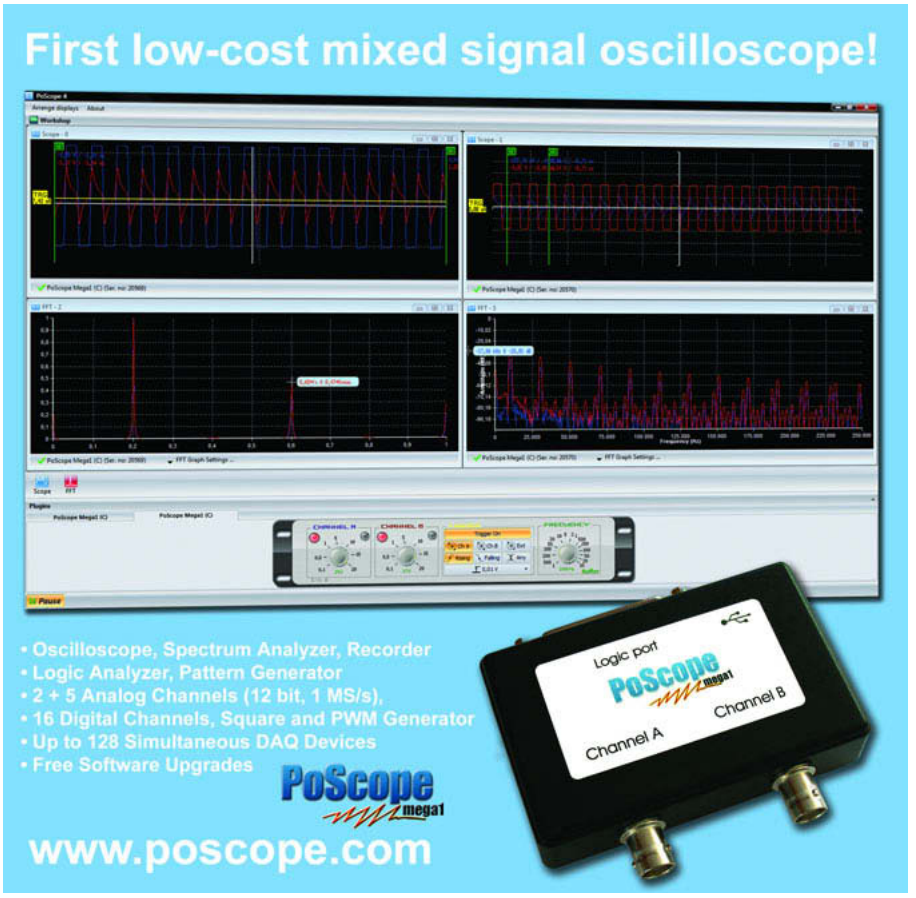
Table 2—The external EEPROM is programmed by the evaluation kit or from an optional HEX file with the phrase table and phrase commands. Here you see a single phrase, 0, with one 24-bit jump vector at location 0, 1, and 2 pointing to address 0x000003. Phrase 0 commands might be 8 or 16 bits in length and often hold additional data like a PCM sample (indicated here by a question mark).

devices up to about 1 Mb (131,072 bytes) in size. That equals an equivalent time of 8 s in PCM mode and 16 s in ADPCM mode.

I can see some of you yawning out there, but wait. Some relatively new flash memory powerhouses have expanded their memory lines with larger devices up to 128 Mb (16,777,216 bytes). These new parts extend the useful file sizes to more than 17 minutes and 34 minutes, respectively. Now we're talking about some useful audio times! Still, I can hear some of you out there saying, "Ya, but these must cost a fortune!" Actually, they are less than $9 per unit.

The KX1400 has a set of I/O pins designed specifically for external SPI communications. Note that these big guns require a 24-bit address, whereas the smaller devices use a 16-bit address. The KX1400 can be configured to handle either address width through the MSIZE input pin. In the block diagram in Figure 1 you will notice the separate Memory and MPU SPI interfaces. Besides these SPI pins, the speaker outputs, and power pins, there are few other necessary connections. MSIZE and MODE (standalone/MCU) inputs make up the configuration inputs. Two general output pins could be used to drive LEDs. These output pins are controlled through the "Set Outputs" command. While you have control of the output's volume through the "Set Volume" command, the Mute and UnMute commands should be used to turn the output off and on to ensure the lowest power consumption. An internal 8.2-MHz oscillator is factory-trimmed and should remain stable over its operating range. The oscillator's output (or a /2, /4, /8 division of it) is available at the CLOCKOUT pin.

At power-up (or a Reset command), the KX1400 will interrogate its inputs to determine operating mode and will wait for instructions from an MCU unless it is in standalone mode. Assuming standalone mode, the KX1400 will then retrieve the address of its first phrase from a list of (up to 4096) jump vectors at the beginning of the external EEPROM device. Note the word phrase is used here to indicate a set of commands. You may simply want to play a PCM file. To do this you might use a single phrase (see Table 2). If you are using the large 24-bit address format, a single jump vector in the first 3 bytes of the EEPROM will point the KX1400 to the fourth byte where it would find an "Unmute" command followed by a "Play PCM" command holding the first 12-bit PCM value in the fourth and fifth bytes of the EEPROM. The sixth and seventh byte would hold the next "Play PCM" command holding the next 14-bit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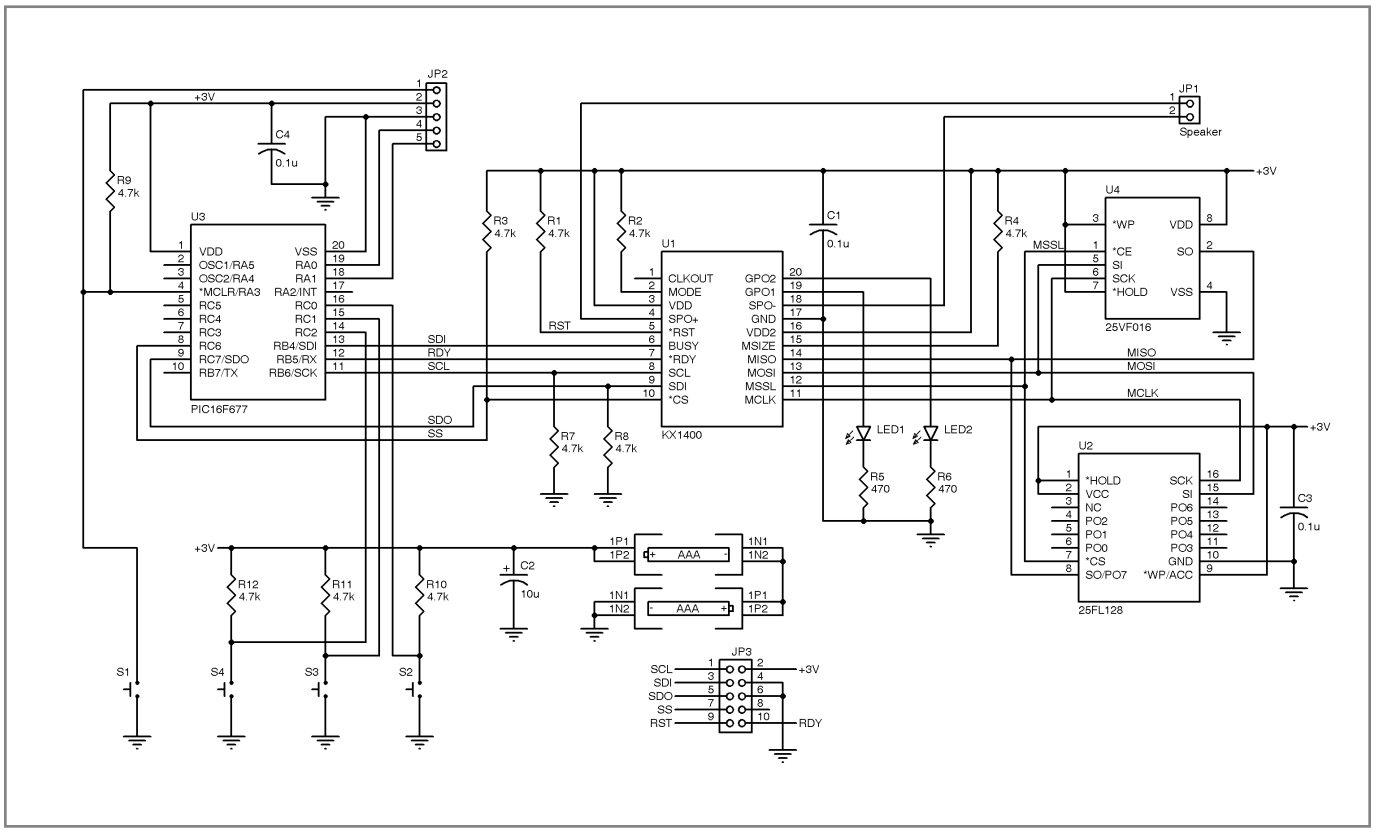

Figure 2—This project uses a microcontroller to access a KX1400 and associated EEPROM to play prerecorded audio files of favorite storybooks. Each story is divided into separate page files that are selected by the user.

PCM value and so on until the file's end is reached. The final command might be a "Stop" command to shut down the audio or a "Reset" command, in which case it would replay endlessly.

MCU

The KX1400 does not have user inputs, but it can be commanded by an external device, usually a microcontroller. A second SPI is implemented to keep communication traffic separated. When the KX1400 is reset and determines it is in MCU mode, it will not fetch the Phrase 0 vector from the EEPROM. It will instead wait for instructions from the microcontroller. Should the microcontroller send a "Play Phrase" command with a Phrase Index = 0 to the KX1400, it will act as if it is in standalone mode executing the fetch and jumping to the vector address for Phrase 0. This doesn't make much sense. But imagine if a number of phrases were stored in the external EEPROM. The list of phrase vectors could be quite long (up to 4,096),

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assuming all the audio clips fit within the allotted EEPROM space.

The microcontroller can determine which phrase is executed and when. If you were not using any PCM or ADPCM data, the external EEPROM would not even be necessary, because these are the only commands that require external data. In fact, you may have noticed that there is a "Play ADPCM (MCU)" command that allows the micro to supply ADPCM data (within each command), instead of fetching it from the external EEPROM. Because an audio file size is rather large, this could really eat up your micro's memory space, but it may be of some use depending on your design.

The application can keep its communication to a minimum by taking advantage of the KX's ability to execute a list of commands for each phrase. Or the micro can minimize the use of the external EEPROM to just PCM or ADPCM data and issue individual commands like "Mute" and "Unmute" directly.

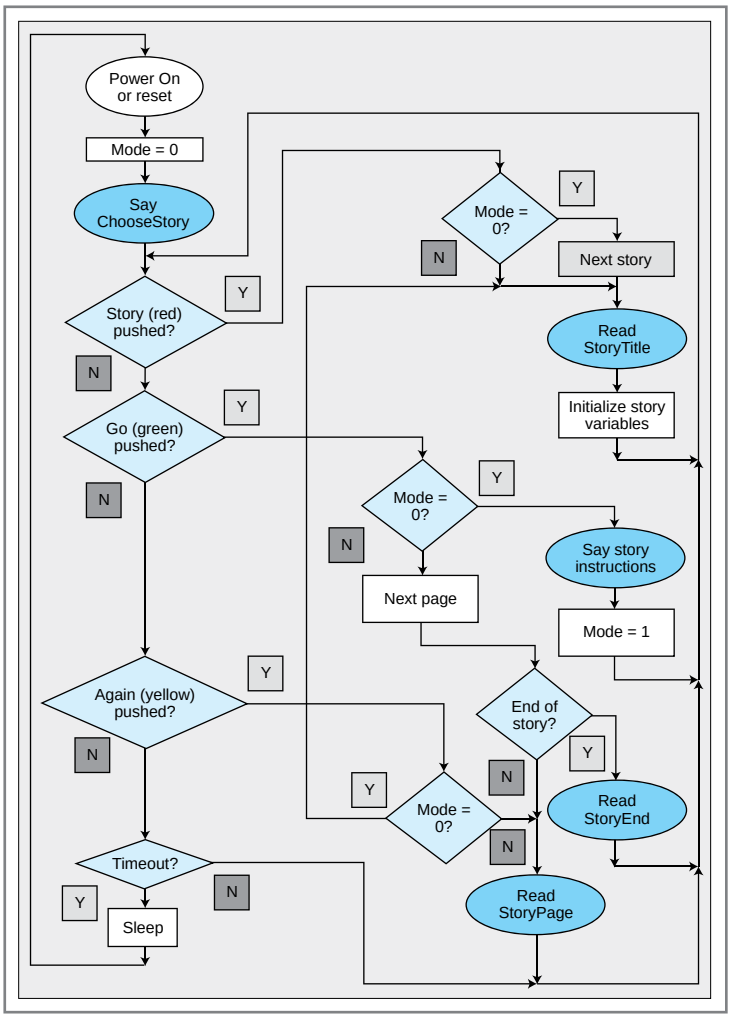

Figure 3—The microcontroller has a few simple tasks. It must monitor the push buttons, keep track of the story and page data, and command the appropriate phrase to be played by the KX1400.

THE PROJECT PLAN

I saw a "recordable book" featured in a Christmas commercial. Hallmark has extended its use of digital record/playback devices for greeting cards and picture frames to storybooks. While easy to use, the device is limited to a physical book—not so much by the printed words, but by the physical design of the page determination hardware. If you haven't seen this ad, you can find it at www.hallmark.com/recordablestorybook. A row of light sensors are uncovered sequentially as you turn each page. This determines which message segment to play/record.

Rather than mutilate a book and mimic this feature (which has some inherent problems dealing with sufficient light), I decided to design this project with push buttons to allow movement between pages. This feature adds some flexibility, such as rereading a page, moving going forward/backward, or even choosing between stories!

Figure 2 is the schematic of this project. The generic SPI interface makes it ease to replicate with just about any microcontroller. I used a low-cost 20-pin Microchip Technology PIC16F677 for this project. There isn't anything unique about this part except that it can operate down to 2.0 V. This allows two AAA cells to power the circuit without the need for any regulation. One of the four push button switches is a reset, which is used as a power switch and brings the system out of power-down which sleeps at less than 1 µA. The other three push buttons are used as function keys. Note also that there is a 2×5-pin header that contains the signals necessary to interface with KX USB-710B programmer. This programmer comes along with the KX1400 evaluation board. This low-cost evaluation kit (less than $50) has a working KX1200 and EEPROM, and it comes with a KX1400 IDE application for the PC, giving you all the tools you need to build EEPROM files and download them into external devices.

IDE

The Keterex application helps you by organizing all of the data necessary to your application in a sequential file that will be programmed into the external EEPROM (see Photo 1). In this project, most of that data comes as WAV files. It is necessary to define a sequence of commands for each phrase. A sequence might consist of unmuting the speaker, playing an ADPCM or PCM WAV file, muting the speaker, and going into low-power mode. You can see the last sequence of my project, Story4End, defined in Photo 1. Just below this sequence is the beginning of the playlist. This is a sequential list of phrase pointers from 0 up to 4095 and the associated sequence that will be executed when requested by your application. Note that these four stories require 72.5% of the EEPROM, leaving enough room for a fifth book.

Packaged with the Keterex IDE is an audio application that can be used to record the WAV files for your

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application (see Photo 2). Audacity has some great tools besides just recording and saving the WAV file. You can pass a file through an amplify algorithm to assure maximum audio output. And, as this raises the noise floor, you can select those areas of no speech and silence the passages, effectively getting rid of the noise. Preview your recording alterations and save the WAV file with the appropriate file name after each phrase's recording session. Note that this project requires over 130 phrases to be recorded, with each of the four stories averaging 30 pages. While that sounds like a lot of work, it goes pretty quickly with the easy-to-use tools provided with the KX1400 evaluation kit.

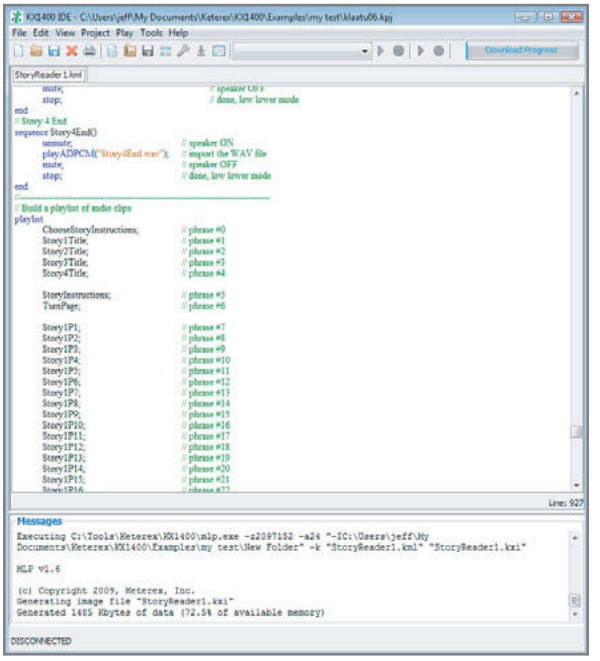

Photo 1—The Keterex IDE uses a scripting language KML to create a phrase list by processing a sequence of KX1400 commands for each phrase. The (Story4End) sequence of the commands is defined just above the PlayList or sequential list of all of the phrases used in this application.

PROJECT APPLICATION

The application for this project runs on a small microcontroller. I think I could've crammed this application into an eight-pin chip, but I didn't want to have to multiplex all of the switches using a single analog input. So, I chose the PIC16F677, which costs around $1 and has plenty of I/O left over for tasks I haven't even dreamed up yet. Besides switch inputs, only five I/Os are required to interface with the KX1400. Actually, you can get by with only four of those five lines. The Busy and Ready lines are slightly redundant. The Ready line indicates when a new command can be received, while the Busy line indicates when the KX1400 has finished executing any received commands.

I purposely left off a power switch. The low-power mode of the KX1400 and PIC16F677 are entered once a timeout has been reached without any push buttons pressed. Take a look at Figure 3. You'll note a couple of things. One, there are two modes, mode 0 for choosing a story

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and mode 1 for reading the story. And two, the main routine only tests for three push buttons. That's because the fourth button is tied to resetting the microcontroller. Pushing it restarts the application (brings it out of sleep). It resets the mode to 0 and reads the instructions on using the buttons to choose a story. The Story (red) button is used to read the next story title (in mode 0) or reread the title of the presently selected story (in mode 1). The Go (green) button is used to select the present story, change the mode, and read the instructions on using the buttons to read a story (in mode 0) and to increment the storybook's page and read it (in mode 1). The Again (yellow) button rereads the present story title (in mode 0) and the present page (in mode 1).

A number of phrases are called directly. The instructions, "turn the page" sound effect, story titles, and story (first) pages are identified from the playlist. By keeping track of the present and maximum count of stories and pages for each story, the application can figure out how to handle a request. When incrementing through the title selections to choose a story, the maximum story count determines the end of the list and resets the title pointer to the beginning.

By placing audio files for each story page in sequential order, the phrase command is easily incremented once it is initialized with the first page of the chosen story. When reading the story, the maximum page count determines when the end of the story occurs and decreases the page count to prevent an unknown page fetch.

CONSTRUCTION

When I saw the Serpac CA series of enclosures, I thought it would make a good home for this project. Having just finished a project where I etched my own PCB, I wanted to get something in hand right away, so I made this PCB as soon as I did a schematic and layout to fit the CA enclosure (see Photo 3). The CA-10 has room for a couple of AAA batteries, but it's tight. This prototype was made with

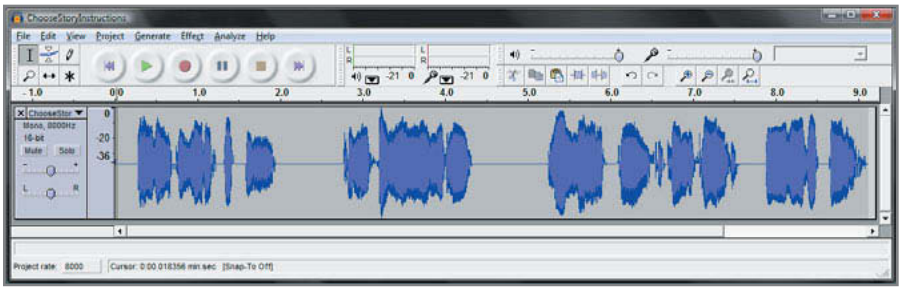
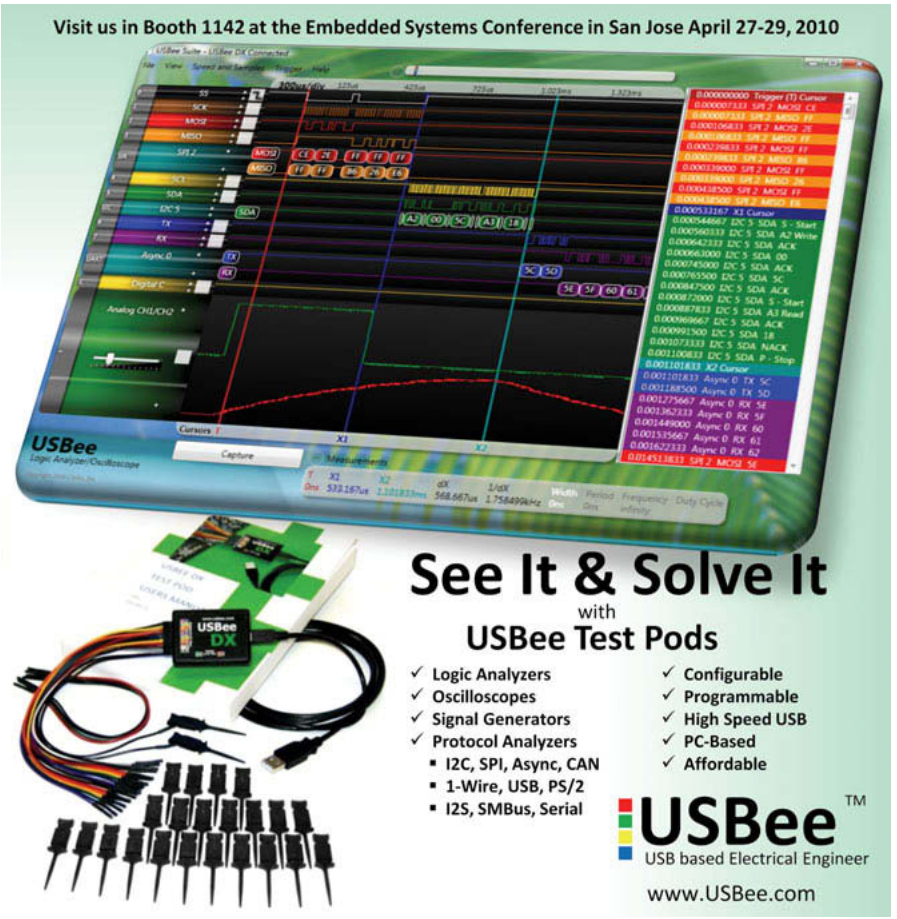


Photo 2—The Audacity digital audio editor makes it easy to record, edit, and save each WAV file used in your application. This 9-s audio file instructs the user on the button functions for selecting a story.

DIP sockets for the microcontroller and EEPROM so I could change them. Headers allow the microcontroller and EEPROM to be programmed on-board, so SMT parts could be used in the future.

Besides the audio work, determining which speaker to use turned out to be a chore. I bought about a dozen various small speakers from 0.25 to 3 W to find a good match and was fairly disappointed with most of them. I found the KX1400's internal class-D audio driver to be barely usable at 3.3 V, 120 mW (320 mW at 5 V). While a larger 4" speaker produced an output that was adequate, the smaller ones that could be mounted in the CA enclosure did not have the oomph to show off the great playback fidelity possible with the KX1400.

Presently, a microcontroller cannot receive information back from the EEPROM. There is, however, a pass-through mode that I have not implemented. In that mode, the microcontroller could place the KX1400 into pass-through mode (setting a configuration bit in the reset



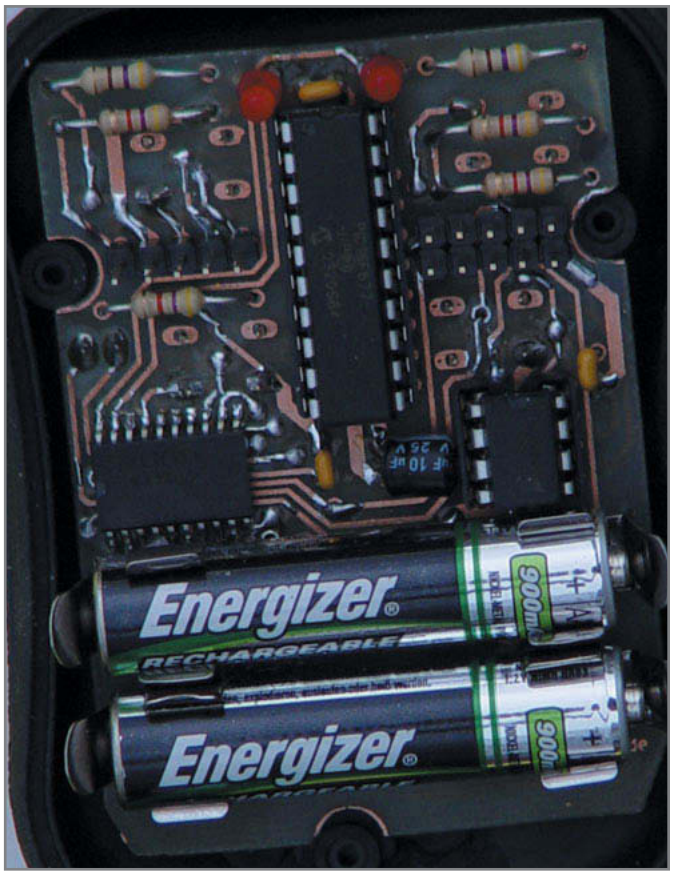


Photo 3—My homemade PCB for this project is designed to fit in the Serpac key fob enclosure. The speaker used here doesn't do justice to the high-fidelity output available from the KX1400.

command), access the EEPROM directly, retrieve any data necessary, and hardware reset the KX1400. This would require some circuitry changes (plenty of I/O pins left). My thought here was to create removable EEPROM modules that could hold other prerecorded stories. The reason for needing to read some data from the EEPROM has to do with keeping track of the stories and pages within EEPROM. Without being able to read some configuration data, there is no way of knowing how many stories and pages there are in the playlist. Although I could use some of the extra I/O pins to allow configuration inputs, it would be nice to have all of this work automatically, and I'd like to be able to use (write) a more generic application.

I already chose a second-generation design configuration. It features a long clipboard to hold the book with the electronics built along the bottom of the board. This would provide a larger area for a better speaker and it could use a thumb drive for the audio files. The KX1400 can be used without an external EEPROM, as long as the microcontroller can keep feeding it the audio commands (samples) fast enough. The thumb drive could, in fact, hold a configuration file making it all work automatically. Hmm. Keeping the external EEPROM might work into this scheme as well. Without the thumb drive attached, the external EEPROM could hold the basic instructions and sound effects as well as a starter story. I could then use the thumb drive specifically for audio clips!

Now, for the rest of the story that I started at the beginning of this article: "Merlin's solution made the king very happy. Even when he was away slaying dragons, the children of the kingdom were comforted by the sound of his royal voice reading their favorite bedtime stories. Everyone in the kingdom slept happily ever after."

Jeff Bachiochi (pronounced BAH-key-AH-key) has been writing for Circuit Cellar *since 1988. His background includes product design and manufacturing. You can reach him at jeff.bachiochi@imaginethatnow.com or at www.imaginethatnow.com.*

SOURCES

KX1400 Audio playback IC
Keterex, Inc. | www.keterex.com

PIC16F677 Microcontroller
Microchip Technology, Inc. | www.microchip.com

PCB "Fab-In-A-Box" Kit
Pulsar Professional FX | www.pulsarprofx.com

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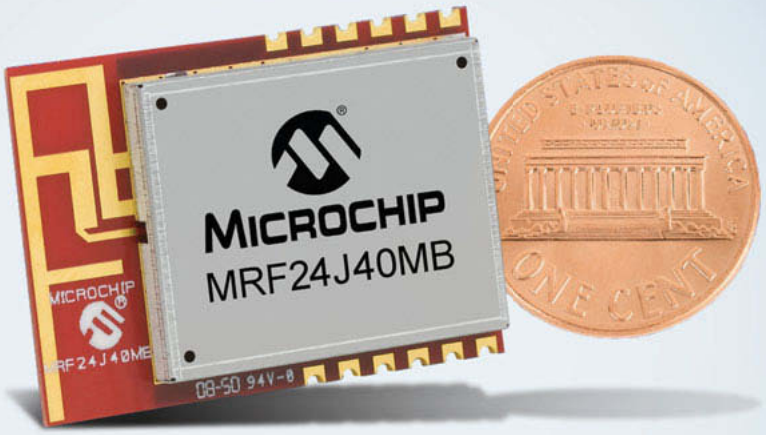

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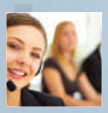

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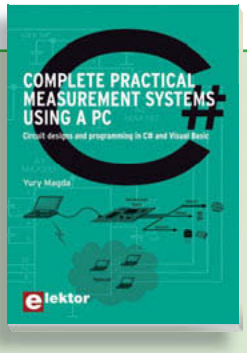

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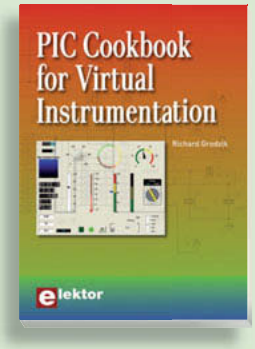

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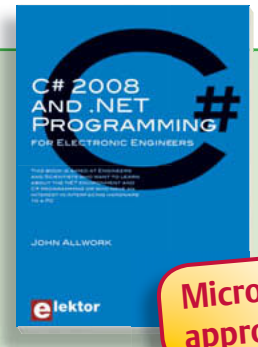

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by Peter Montgomery

Serial Network Hub (Part 2)

Circuit Design and Usage

You are well on your way to building a six-port RS-485 hub that can implement a network packet system. Here you learn the details about the software and hardware, as well as some hidden "gotchas" present in RS-485 chips.

In the first part of this article series, I described my need for an RS-485 hub as part of the hardware running my yearly Halloween display. A quick visit to my website (www.socalhalloween.com) will show you the level of sophistication in my computer-controlled show, which includes multiple animatronic figures having conversations as well as physical effects, sound effects, and more. The system is run by a laptop connected to a series of daisy-chained hardware nodes that communicate via RS-485. Normal RS-485 network topologies run either half-duplex—with all transmitters and receivers connected to a single wire pair—or full-duplex—with a master node transmitting to all slave nodes on one wire pair, while listening to all slave nodes on a separate wire pair. In either case, only a single slave node can transmit at a time, and some mechanism (polling, token passing, etc.) must be implemented to prevent multiple slaves from transmitting simultaneously and destroying each other's packets. I originally implemented a "store and forward" scheme on each slave node to allow slaves to transmit whenever they needed to, but it required extra circuitry, complicated the software running on each node, and introduced increasing time delays for slave nodes sending messages to the master node.

My ultimate solution was to build a six-port RS-485 hub that implemented my Halloween network packet system and allowed me to greatly simplify the wiring of the nodes. The design criteria included writing as much code as possible in C, minimizing the number of UART chips (the hub has six ports) on the PCB, building a device that has its own power supply in the case (no wall warts!), and building a device that is small and professional-looking. Did I succeed? Let's find out.

CIRCUIT DESIGN

Like everyone else who does this kind of stuff, I have my personal favorite processors. My processors of choice are

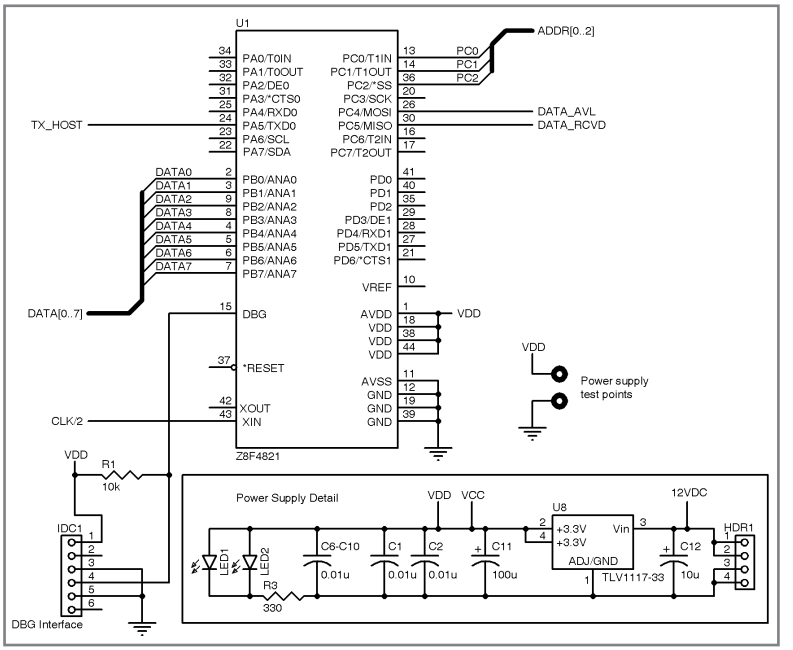


Figure 1—This is the Z8 portion of the Serial Network Hub. It manages all the packet buffering and communication.

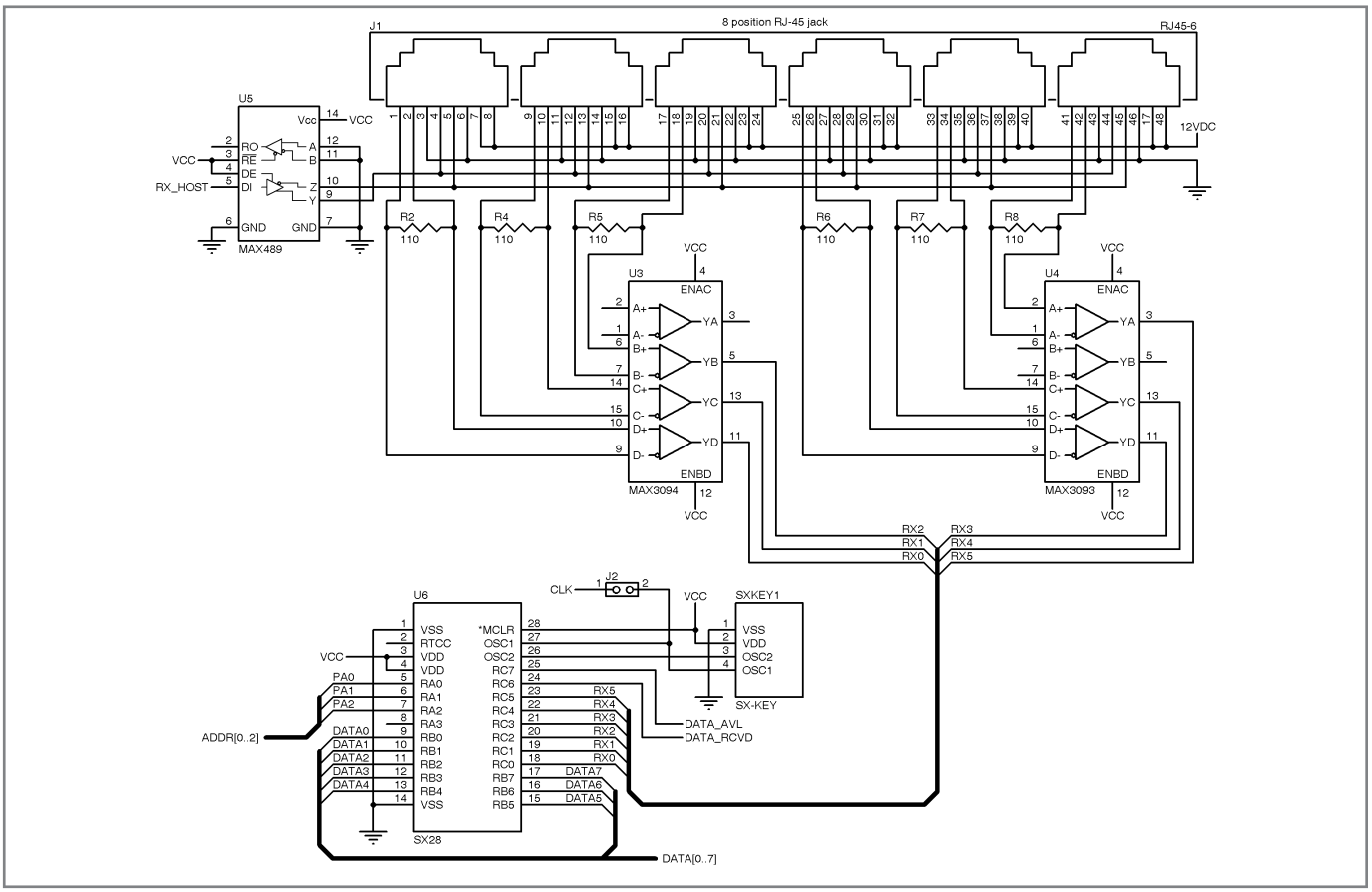


Figure 2—This shows the S portion of the hub, which is responsible for implementing a six-port UART in software. The MAX3083 chips handle the RS-485 level conversion.

the Zilog Z8 Encore! and the Parallax SX chips. The Zilog Z8 is an 8-bit chip that lets me code in C, using a free IDE and compiler provided by Zilog. The IDE and chips support hardware debugging at the C source or assembly language level. The parts range from eight-pin to 68-pin devices, with EEPROM from 1 to 64 KB and up to 4 KB of RAM. They come in through-hole or surface-mount parts, and nominally run at 3.3 V while accepting a range from 3 to 3.6 V.

The Parallax SX is a more unique beast. Running at speeds up to 75 MHz (and up to 75 MIPS) and featuring a jitter-free, deterministic interrupt scheme, they are almost FPGA-like in their abilities. The interrupt system is where the power of this chip lies. The SX chips have an 8-bit real-time clock counter (RTCC) with prescaler that generates interrupts at pretty much any interval you desire. Unlike pretty much every other CPU on the market, the SX always takes three clock cycles to enter or exit the RTCC interrupt regardless of what instruction the processor is executing at the time. Further, there is an exit opcode which lets the chip automatically update the timer value to account for the number of cycles used during the interrupt handler, regardless of whether the interrupt code path was longer or shorter for a given interrupt. Imagine that you've set the RTCC interrupt to occur every 129 clock cycles, and that the interrupt handler takes anywhere from 51 to 69 clock cycles depending on what it does during the interrupt. Regardless of the exact number of clocks that the interrupt handler uses on a given interrupt, the special exit opcode will automatically reload the RTCC counter with the correct value to make the next interrupt happen exactly 129 cycles from the previous interrupt. These two features (fixed interrupt latency and the special exit opcode) provide a completely jitter-free interrupt period. Because of this feature, the SX allows you to create virtual peripherals that are rock steady. For example, if you want a PWM generator, you write one that runs in the interrupt handler. Want a UART? Same approach. Want six UARTs? Just make sure the code to execute them can complete in the time between interrupts and you can have them. Writing software lets you make the chip do what you need it to do, rather than have a lot of extra peripherals on board that are either insufficient or over abundant for the needs of a particular design.

A Zilog Z8F4821 CPU controls and coordinates everything (see Figure 1). The circuit shown in Figure 2 has a Parallax SX-28 acting as a six-receiver port UART. Both parts will run on a 3.3-V supply, so I didn't need both a 5- and a 3.3-V source. The power is supplied by a Texas Instruments TLV1117 linear power regulator in a SOT-223 surface-mount package. Extra PCB copper was used to provide heatsinking. This was especially important since the input voltage to it was 12 V, which meant dissipating more power

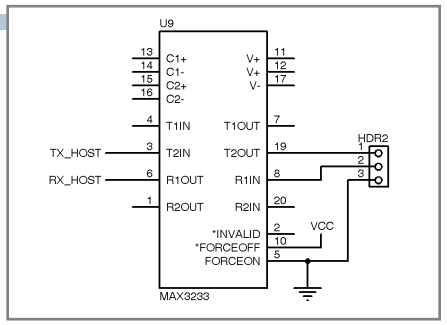


Figure 3—A MAX3233 provides conversion from RS-232 level to 3.3-V logic without requiring external capacitors for the charge pump.

in the form of heat. Signal conversion from logic to RS-485 levels was handled by a pair of Maxim MAX3094 quad receivers and a MAX3070 transceiver. A MAX3233 chip provided logic to RS-232 level conversion, and required no outboard capacitors for the charge pump, reducing component count (see Figure 3).

I spent a bit of time working out the best approach for clocking the two CPUs. The SX can be run up to 75 MHz, but the Z8 tops out at 20 MHz.

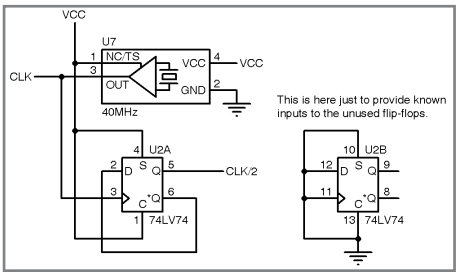
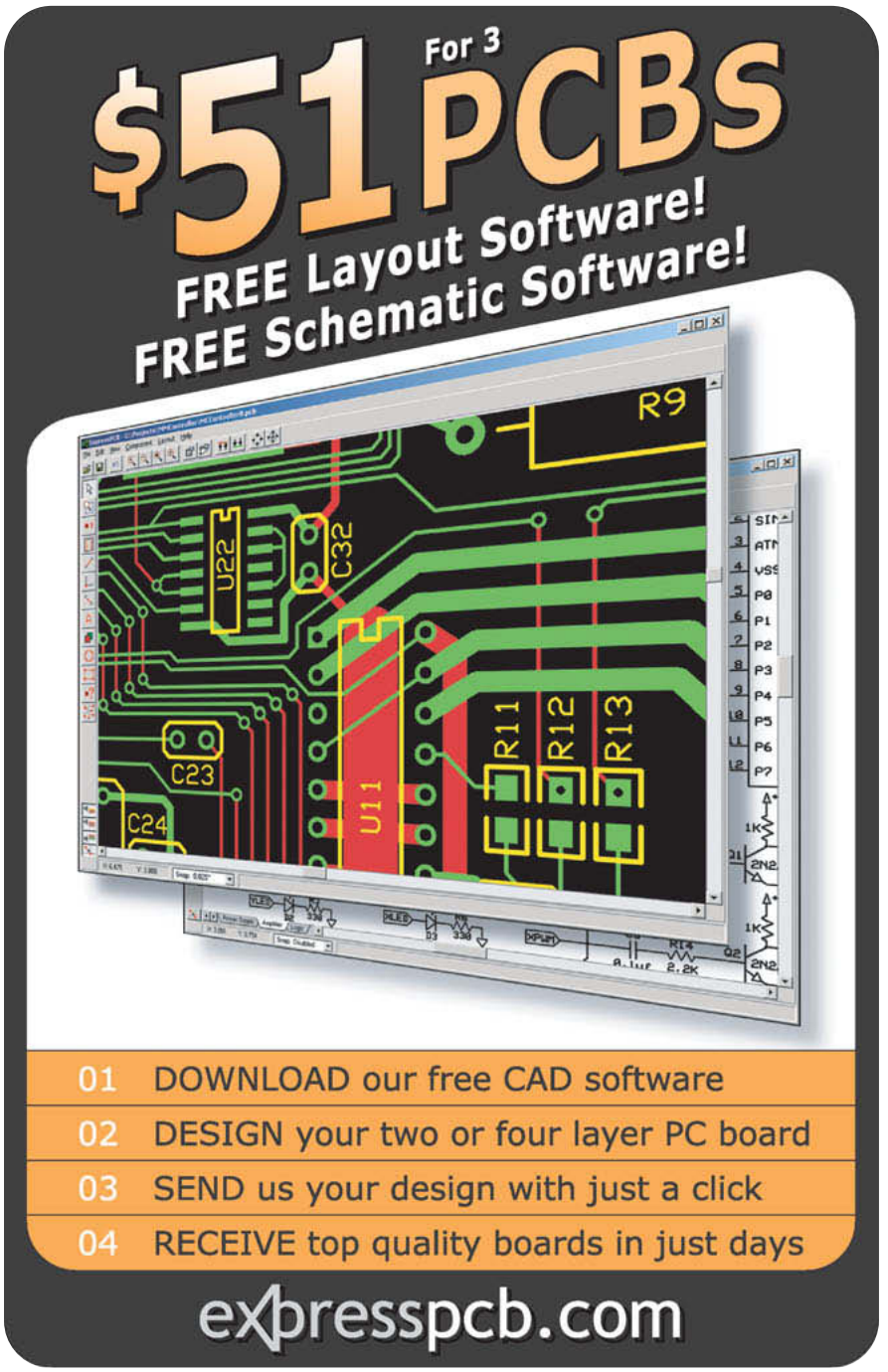


Figure 4—The project needs a 40-MHz clock for the SX and a 20-MHz clock for the Z8.

I wanted to run the Z8 around 20 MHz for maximum performance, but if the SX ran at that speed, it would have insufficient speed to run all six UARTs in software. I also wanted to keep power consumption down where I could, so I didn't want to run the SX at too high a speed. After writing the code for the SX, I could determine how many cycles the interrupt took. Using this information, I decided to run a 40-MHz master clock, which feeds the SX directly, but pass it through a simple divide by two flip-flop circuit to give the Z8 a 20-MHz clock (see Figure 4).

The SX was the perfect chip for me to create a six-port UART. In my design, I run the SX with an interrupt rate of 307.692 kHz. When you're running the interrupt at over 300 kHz, you know you're using a fast chip. The interrupt code executes six software UARTs sequentially, each with an 8-byte ring buffer, and each operating at 4× oversampling to detect the start bit properly. The main code running in the foreground monitors the ring buffers. When a buffer for a UART has added a byte to its ring buffer, the foreground code sends it to the Z8 using an 8-bit-wide parallel transfer using a lightweight handshake scheme.

The handshake scheme simply uses an input and output bit on each processor that is cross-wired (input to output) between the two chips. The scheme doesn't use the absolute value of the bits, but instead whether a bit has changed state to indicate an event. At start-up, each processor's output bit is set to a known state. Each processor reads that initial state and stores it. It then polls the bit and compares the current state to the stored state. When a processor changes the state of its output bit, the other processor detects the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Listing 1—This code for the Z8 to SX data transfer handshake scheme runs on the Z8. It shows extensive use of macros to simplify code readability and ease of modification.

```
// This macro generates a bitmask for the passed bit number
#ifndef THIS_BIT
#define THIS_BIT( bit ) ( 1 << (bit) )
#endif // THIS_BIT

// Port E, bit 4 is data ready signal from the SX
#define DATA_RDY_IN_PORT PEIN
#define DATA_RDY_BIT 4
#define DATA_RDY_FROM_SX DATA_RDY_IN_PORT & THIS_BIT(DATA_RDY_BIT)

// Port E, bit 5 is the acknowledge output bit
#define ACK_OUT_PORT PEOUT
#define ACK_BIT 5

#define ACK_TOGGLE            ACK_OUT_PORT ^= THIS_BIT(ACK_BIT)

   char CurrDataReady; // Current state of data ready line from SX
   char PrevDataReady = 0; // Previous state of dtat ready line from SX

   while(1){
      CurrDataReady = DATA_RDY_FROM_SX; // Get state of ready line from SX
      // Has the SX Data ready line changed state?
      if (CurrDataReady != PrevDataReady){
         ACK_TOGGLE; // Yes, so tell SX we got the data
         PrevDataReady = CurrDataReady; // Note state for next time
      }
   }
```

change by comparing the new input state to the previously stored state. This new state is then stored, and the process repeats.

Since data flows unidirectionally from the SX-based UART to the Z8, the SX changes state on its output bit when it has a byte to transfer. The Z8 sees the change, reads the byte, and then changes the state on its output bit. This change from the Z8 lets the SX know it is safe to put a new value on the 8-bit transfer port as soon as one is ready. Using some simplified test code, I clocked the two processors sending data synchronously at 186 KB per second. The code snippet in Listing 1 shows the C language code used by the Z8. Note the extensive use of macros. Since talking to ports, setting bit directions, and other actions are very hardware-specific, I used macros to isolate

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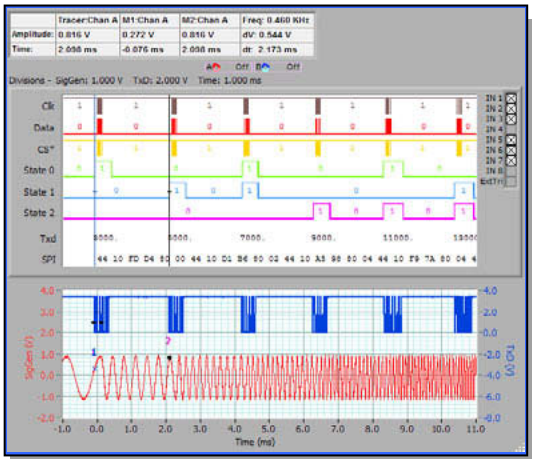
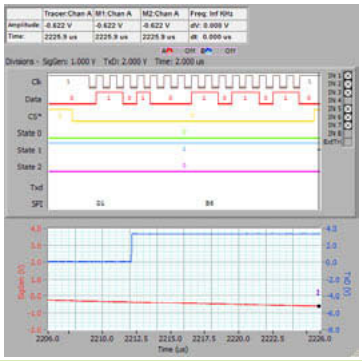


Example:
State based toy with sound. As each state is exercised, the controller sends an SPI message to the sound generator. Here a sinusoid is used for testing, Both the SPI message, and Uart test string are decoded and displayed. We triggered on State 001.

Zoom on the tracer, SPI decoded as D1 B6



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the logic from the chip-specific details. If I move to a completely different processor, I can update the code by changing only the macros. These changes are then propagated to the rest of the code during compiling, rather than manually hunting through the source code for the hardware-dependent sections. It also helped me when I moved from the development hardware to the final hardware and completely changed the port and pin assignments in the process. The macros also make the working part of the code incredibly easy to read.

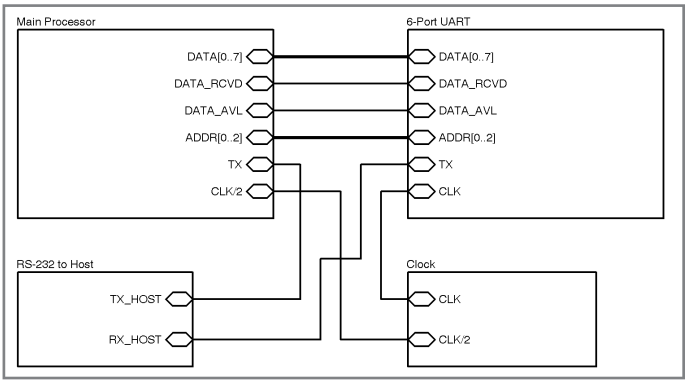


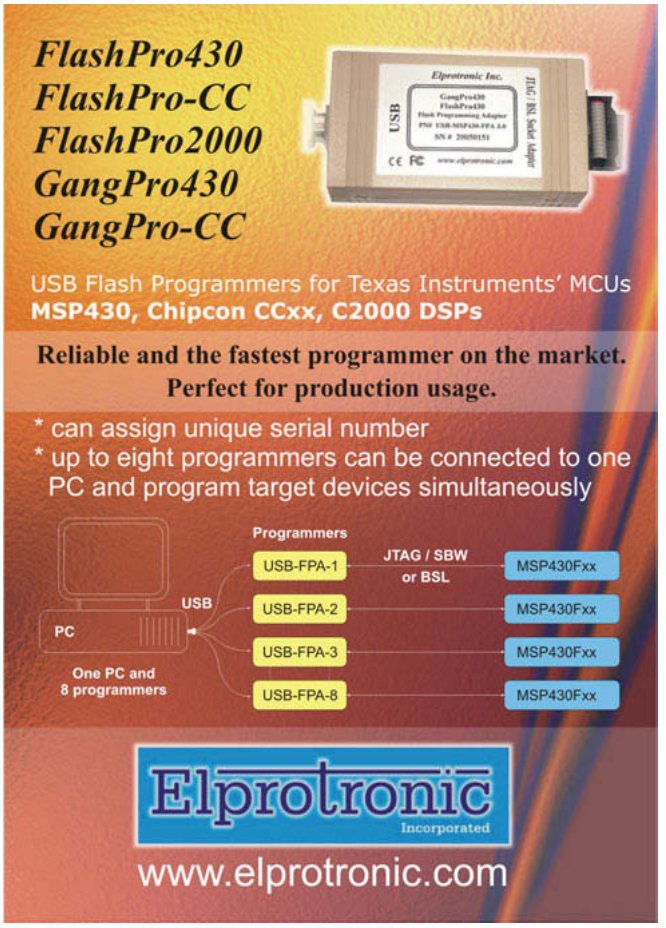
Figure 5—Top-level connections for the serial network hub

The Z8 was a great chip to use as the CPU in charge. With 48 KB of EEPROM and 4 KB of RAM, I had plenty of room for code and buffering. It turns out that the code for the Z8 barely made a dent in the EEPROM, using only 3 KB. However, it wasn't really an option to use a smaller part as the smaller Z8s have less RAM, and RAM was something I wanted to have plenty of. The Z8 has to retrieve each byte of data from the SX and store it internally in a ring buffer dedicated to that UART. It then monitors each ring buffer to see if it has a completed packet. When it finds a complete packet, the Z8 uses one of its hardware UARTs to send it to the laptop. Since I wanted to give each UART a 256-byte buffer, the RAM needed for buffering alone took up 1.5 KB.

CONSTRUCTION

Just as I did with the Halloween Remote, I wanted the serial network hub to look as good as it worked (see Photo 1). Looking good meant having an attractive enclosure with well designed and machined panels. For the enclosure, I chose a small extruded aluminum unit from Hammond. It's a black anodized enclosure that's only 4″ × 4.75″ and 1″ tall. For the front and rear panels, I used Front Panel Express once again. Their software is quite easy to use, and the total cost for the front and back panels was less than $75. This was for a pair of blue anodized panels with custom machined openings for the various connectors and switches, as well as yellow text and a skull logo I designed in white.

The power supply for the hub was something I didn't design. I needed the smallest power supply I could find. I selected a MEAN WELL Enterprises NFM-20-12 switching power supply that provides 12 V at 1.8 A in a board 0.75″ tall and only 3.5″ × 2″ in size. I wanted



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to make sure this was a safe device to operate, so I used a breaker in line with the power supply. Oddly, this was one of the trickier elements to find. Most small panel breakers have a tiny face but are over 1″ long. Since I was trying to cram this project into a small case, the typical breaker would collide with the power supply. I finally found a small breaker (made by E-T-A Circuit Breakers) that was wide behind the panel but not deep.

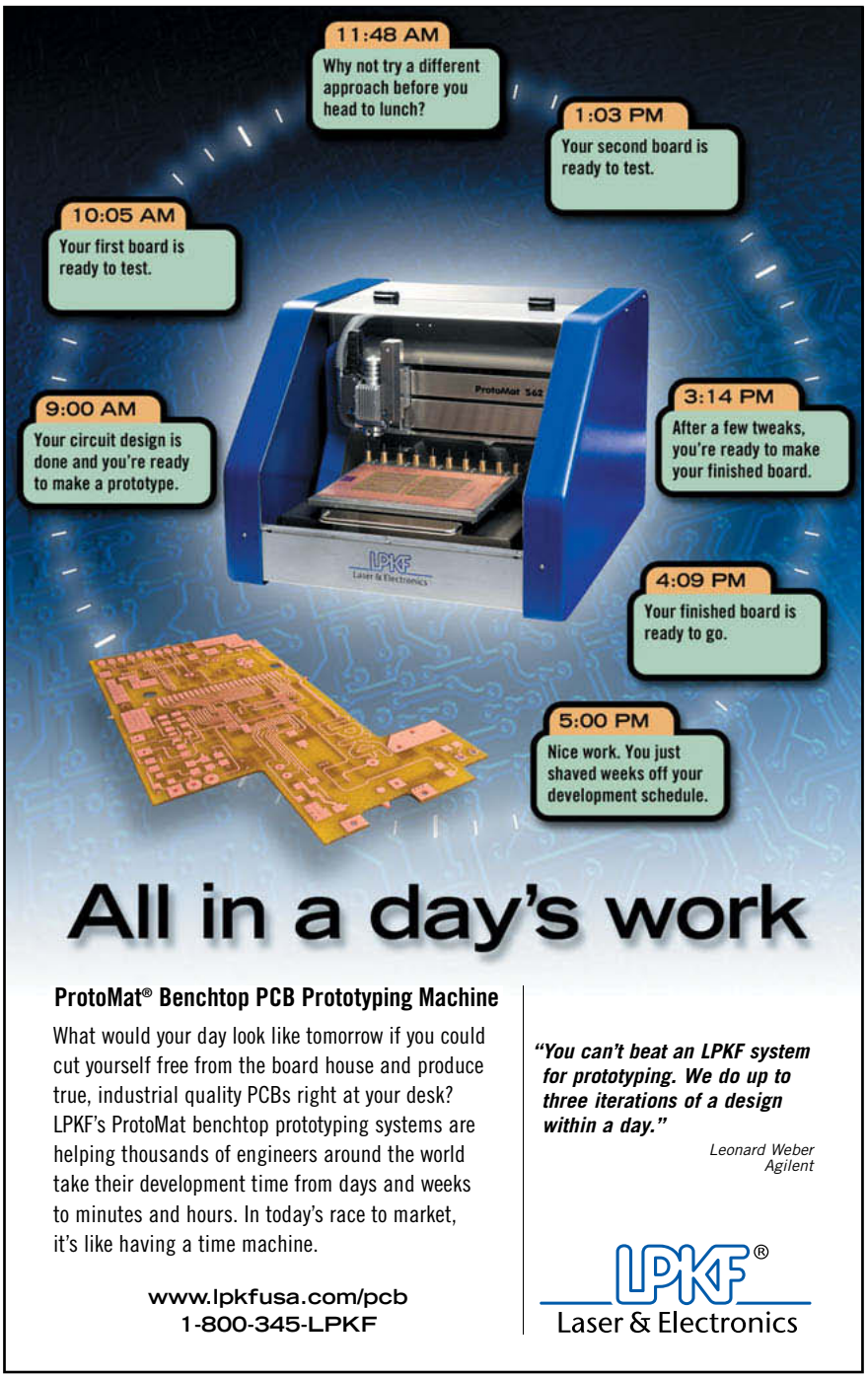
Photo 1—The board in the middle is the MEAN WELL power supply, while my PCB with a six-port RJ-45 jack is on the right. Note the attention to detail on the internal wiring.

The PCB layout was a bit tricky. While the board needed to be the full 4″ wide to fit in the slots of the extruded aluminum, the length was another story. The power supply took up 2″ of the space inside the enclosure, while the switches, breakers, and power input took up almost another 1″, leaving a maximum of about 1.75″ for the length of the PCB. Complicating things further was the fact that the RJ-45 jack required 0.69″ of space on the PCB, thus cutting my room for components down to about 1″.

On the plus side, I didn't have a ton of components. On the negative side, I didn't have a lot of room. The solution? Surface-mount components and a generous use of both sides of the board for component layout. Rather than the typical component-side/solder-side style of board layout, I put components on both sides of the board as needed. I kept the top side populated with the through-hole-only devices, such as the jacks and headers, as well as the surface-mount processors and linear power regulator parts. The bottom of the board was for all the RS-485 interface chips and terminating resistors. So, I had a finished PCB. The result was tricky to lay out, but worth it for the space savings it generated.

PCB LESSONS

I have used the SX-28 chip in numerous projects, but it has always been the through-hole DIP package. When I decided to make this PCB an all surface-mount design, I checked the documentation for the SX-28 to see if the pinout was the same for the DIP and surface-mount packages. In the documentation I read, the pinout was identical for both the DIP and SOIC packages. Simple. I


11:48 AM
Why not try a different approach before you head to lunch?
1:03 PM
Your second board is ready to test.
10:05 AM
Your first board is ready to test.
9:00 AM
Your circuit design is done and you're ready to make a prototype.
3:14 PM
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proceeded to lay out the board and then sent it to be manufactured. When I got it back and started adding parts, all the testing went great until I added the SX-28 to the PCB. Suddenly, the power LED was dim (indicating a heavy load) and the SX-28 got extremely hot very fast. I had overlooked a minor, but critical, detail. The SX-28 comes in two different surface-mount packages—SOIC and SSOP. While it's true that the DIP and SOIC packages use identical pinouts, I was using a chip in the SSOP package. Sadly, the SSOP has a very different pinout. I ended up having to correct the parts in the schematic and PCB software, modify the layout design, and then get a new PCB manufactured.

Another lesson learned involved the MAX3094 RS-485 quad receiver chip. On page 1 of the datasheet, it says: "When active, these receivers have a fail-safe feature that guarantees a logic-high output if the input is open circuit." This definitely made life easier since I didn't have to worry about what the chip would do when nothing was attached to the inputs of the chip. After I got the revised PCB, I proceeded to add parts to it and test it as I went along. Electrically, the board was solid, with no parts overheating or exhibiting strange behavior. I then downloaded the code into the SX-28 and Z8 Encore! chips and immediately discovered strange behavior.

If I plugged a device into the hub but the device didn't send any data, the SX-28 was seeing a stream of zeros flooding in on that UART. Some time spent debugging the hardware revealed that until the first byte was received, the MAX3094 receiver was stuck with the output low, causing the UART to view it as a stream of zeros. I reread the datasheet in detail and discovered (buried on page 10) that the super-handy "fail-safe" behavior actually fails if the input is terminated. Since it is an absolute requirement of the RS-485 spec that the last receiver is terminated and a hub is by default the last receiver, then all the RS-485 receivers in the hub exhibited this bad behavior.

It seems to me that calling something "fail-safe" which is actually guaranteed to fail simply by following the electrical spec of RS-485, kind of implies they need to come up with a different name to describe the "feature." I was shocked that this condition wasn't properly handled by the chip. Maxim provides a fix for this that requires adding two more resistors for each input, but that pretty much defeats the whole purpose of the "fail-safe" feature of the chip. Fortunately, since all my MAX3094 chips acted the same way, I was able to work around this bug using a firmware fix, but the correct solution will involve a new layout and PCB with the extra resistors added.

USING THE HUB

The hub performed completely up to my expectations. Not having to daisy chain every device for the display simplified the system layout and wiring. I used one of the ports to run a line to a far corner of the house. This let me plug in the remote without having to drag a monstrous cable behind me while using it. I am especially pleased with the look of the finished device. It looks like something commercially manufactured. Since every single packet has to pass through this device, failure would have caused the entire show to stop running. The strong physical construction combined with an internal power supply meant that the hub just chugged along all night, passing packets and keeping the show alive.

Peter Montgomery (PJMonty@csi.com) spent 12 years working as a visual effects supervisor on films such as Mortal Kombat *and* Ace Ventura: When Nature Calls *before becoming a director. He has directed dozens of commercials and made the transition to episodic television with The Disney Channel's* Lizzie McGuire. *Peter is self-taught in both programming and digital hardware design.*

PROJECT FILES

To download the code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2010/237.

SOURCES

NFM-20-12 Power supply
MEAN WELL Enterprises Co. | www.meanwell.com

SX-28 Proto Board
Parallax, Inc. | www.parallax.com

TLV1117 Linear power regulator
Texas Instruments, Inc. | www.ti.com

Z8F4821 Microcontroller
Zilog, Inc. | www.zilog.com

NEED-TO-KNOW INFO

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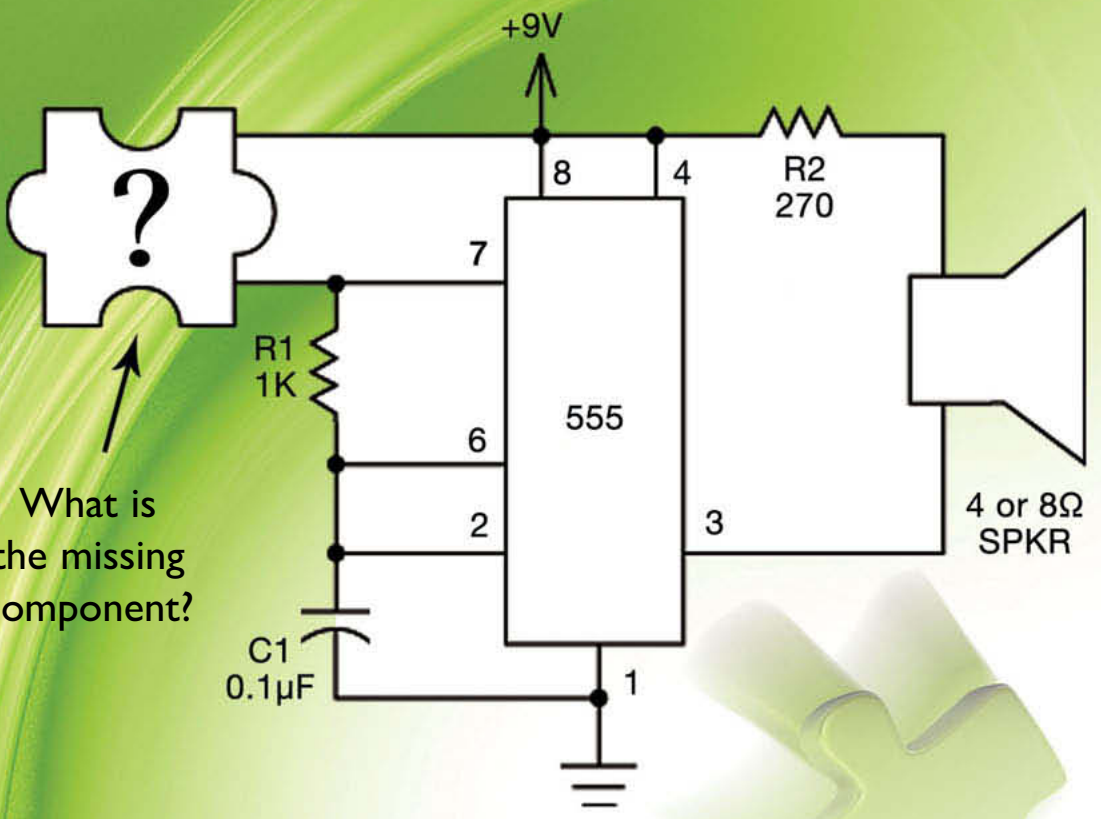
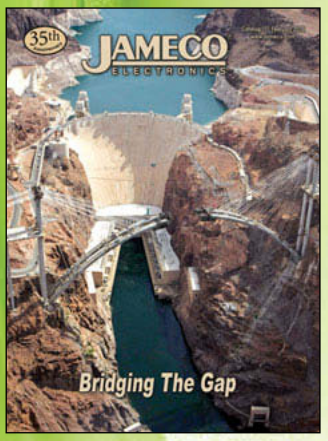
Can You Guess the Missing Component?



What is the missing component?



Amateur electronic musician Joe Rhythm is planning a one-man video concert that he plans to post on YouTube. Controlling his array of instruments requires both hands and he wants to build a pressure-sensitive tone generator that he can control with a free finger or even an elbow or foot. Joe quickly whipped up a simple tone generator using parts from his bench stock. Since, there wasn't enough time to order a pressure sensor, he improvised by making one from materials he had on hand. What did he use? Go to www.Jameco.com/teaser6 to see if you are correct and while you are there, sign-up for our free full-color catalog.

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by Alexandre Ney Guimarães

Smart Control

An Innovative Approach to Reflow Soldering

This new approach to reflow soldering incorporates a toaster with a controller built around an LM35102. The system features a simple graphical display and buttons for starting the cycle.

For years, I successfully used a small toaster oven, with infrared heaters, as a reflow oven for prototyping and small production runs. It worked as well as a large convection reflow oven, except for its speed. Temperature control is more complicated, so I needed an oven with the correct power and proper heat distribution without any cold or hot spots. I set out to build my own.

I'd like to say that my main goal for this project was to build a small portable design, but I'd be lying. I really just wanted to see if it could be done with something as inexpensive as a toaster oven (see Photo 1)! With this project, you can in fact create a design that works as well as an expensive oven. You just have to know how to control the temperature and respect the setup's limits. Big PCBs are impossible to manage, and the toaster has to have an even heat spread capacity to make it work well.

I wasn't trying to build a marketable consumer product, so as I designed the controller, I tried to keep nonrecurring engineering costs to a minimum. Engineering is a problem-solving science, so I always try to remain focused on finding the best solution—yes, even when the idea is as crazy as using a one-off toaster as a reflow oven. Like most of you, I guess I have a "mad scientist" deep inside me.

When I began planning this project, I wanted a portable soldering setup to work as well as a seven-zone reflow oven when used with small boards. I also wanted a cool-looking user interface, and I needed the nonrecurring engineering (NRE) to be low. Those requirements guided my software, hardware, and safety-related decisions.

SMD SOLDERING BASICS

In a large reflow oven with a conveyor belt, the oven is divided into "zones," each of which has separate heaters and temperature control. The board passes through them at a specific time to produce the proper temperature profile. When using a "batch" oven or a bread toaster, you need to make the temperature as close as possible to the manufacturer's recommended profiles. I used the recommended profile for Kester R276 solder paste as a basis for my temperature control procedure. Photo 2 shows the "ideal" profile compared to the results I measured from the toaster. You can see how close I was to the ideal profile, even with a simple algorithm. I didn't even consider PID because the difference from overshooting was not enough to cause any problems in

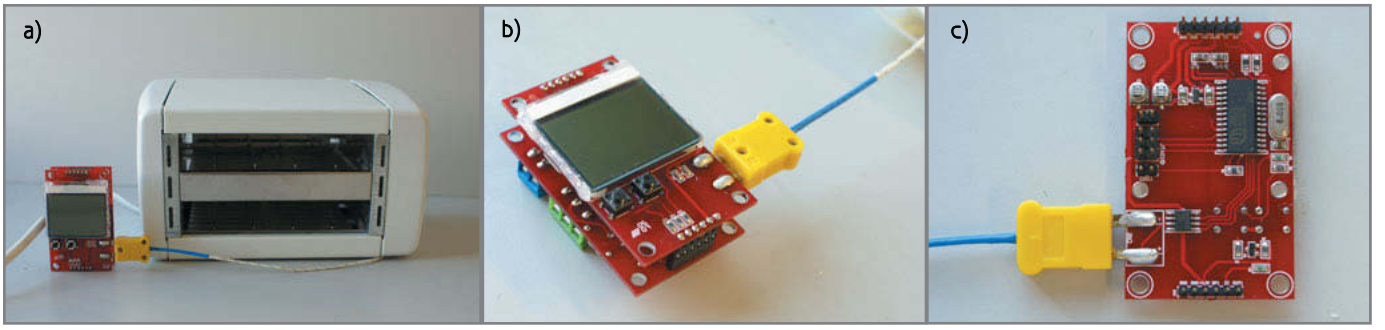

Photo 1a—I used a small bread toaster with a temperature controller on the side. **b**—This is a close-up view of the controller boards with the display. **c**—This is a "logic" board with a Luminary Micro LM35102 and Maxim Integrated Products MAX6675 thermocouple interface chip.

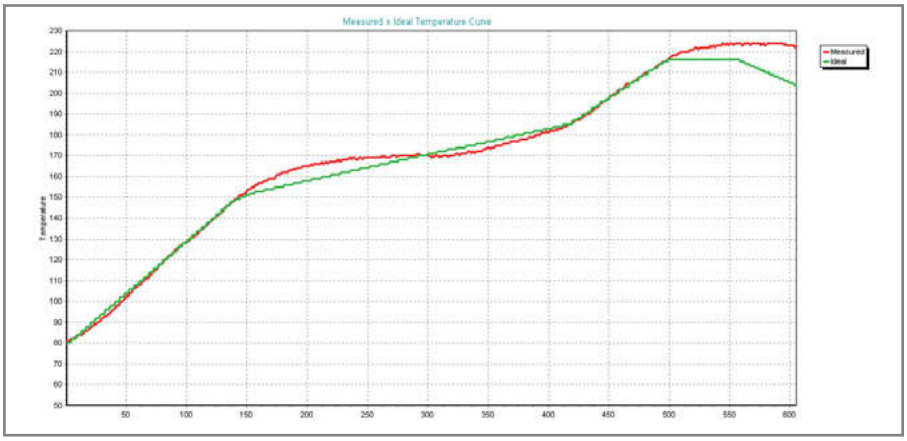

Photo 2—This screen capture shows the "ideal" profile (red) and measured temperature (green).

the soldering process.

I first got the toaster to stabilize the temperature around 80°C to get the system to a point where most of the thermal inertia was gone. After that, there were the usual phases for soldering: preheating, soaking, reflowing, and finally cooling. All the steps of the profile were reproduced nicely, but they took a little longer than a usual reflow profile (as a safety measure). The results were outstanding and even better than some commercial reflow ovens that I've seen with three reflow zones.

HARDWARE DEVELOPMENT

Choosing a controller for this project was easy. As you can see in Figure 1, I went with a Texas Instruments (Luminary Micro) LM3S102 microcontroller because it was inexpensive, C-friendly for such a small CPU, and came with free tools. Most importantly, it had plenty of resources to help keep NRE costs to a minimum. I consider the LM3S102 to be a great 8-bit "killer," especially for small- to medium-sized projects.

For the user interface, I chose a Nokia 3310 graphical display because it was affordable, readily available, and easy to interface (see Figure 2). I included buttons for starting the cycle. Plus, they will make the board more versatile for future projects or expansion. I added a Silicon Labs CP2103 serial-to-USB interface to make development and temperature profiling easier. It was not needed after development and toaster characterization.

To simplify temperature measurement, I used an affordable "K" thermocouple and a Maxim MAX6675 interface chip. The thermocouple was attached to a PCB to help measure the temperature as close as possible to the components and solder paste. Measuring air temperature inside the toaster would not help much! Once more, this decision was driven by the need to lower NRE costs. Using op-amps, cold-junction compensation, and ADCs wouldn't make sense for a small project.

The power section is galvanically isolated, using one AC TPL620 AC optocoupler for detecting the zero-crossings and an MOC3011 optoisolated TRIAC driver. The BTA12-600CW is a snubberless 12-A TRIAC. At the power levels involved here, the zero-crossing activation may seem like overkill, but the pulse-skipping technique keeps switching noise levels down, stresses the TRIAC and heaters less, and allows better temperature control over the full temperature profile.

The toaster I used was one of the cheapest on the market. It cost me $10 and had a PCB inside to control when the toast was ready! I removed the control electronics. This low-cost element of the system performs incredibly well. It has low thermal mass and

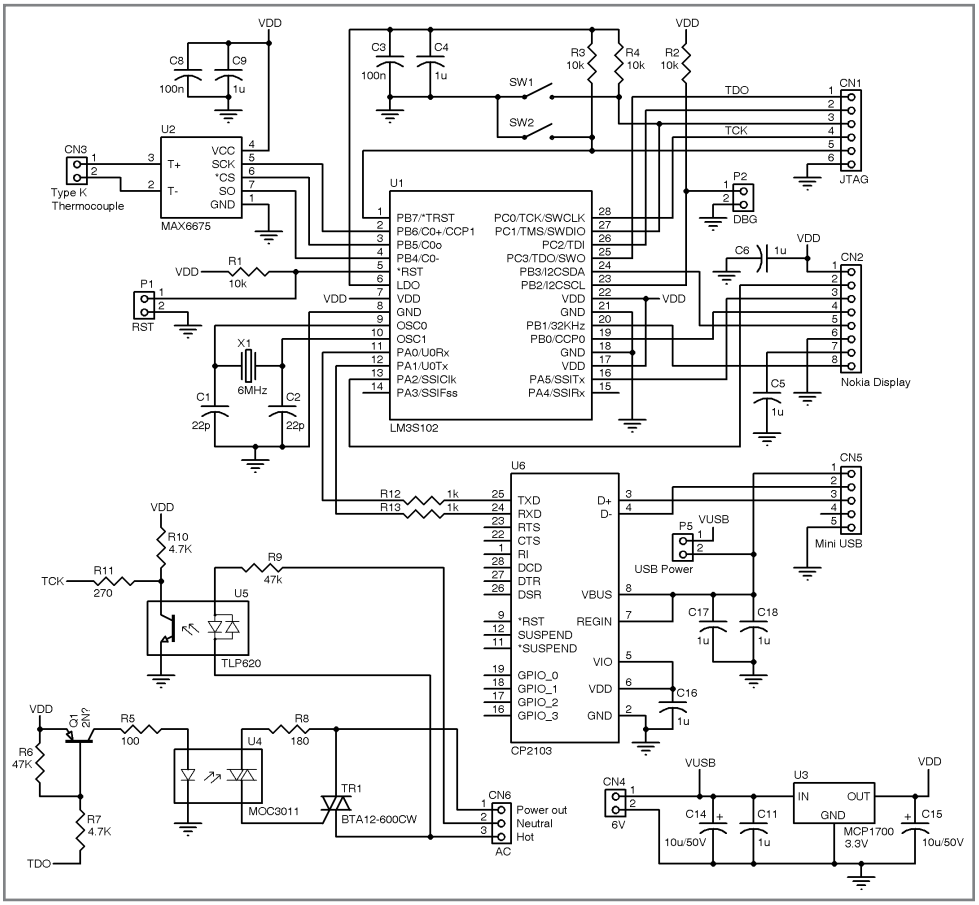

Figure 1—The design is built around an LM3S102 microcontroller. Data is displayed on a Nokia 3310 graphical display.

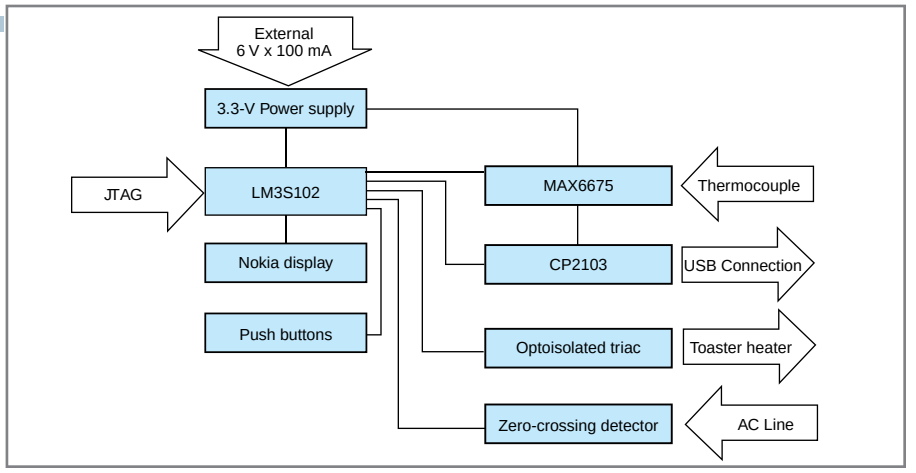

Figure 2—These are the system's main parts. I used a Nokia 3310 graphical display because it was easy to interface.

consequently less thermal inertia than a bigger oven. Plus, the available power per volume is much higher than a toaster oven. It heats and cools much faster than an oven could. Adding a nitrogen "puff" at the right moment to expel most of the oxygen from the soldering atmosphere would also be inexpensive because the volume is so small. That is on my "to-do" list. I already have a spare CPU output to add that function. Using nitrogen improves the "wet-ability" of the solder paste and reduces oxidization. A nitrogen atmosphere toaster is a nice idea for the future.

POWER CONTROL STRATEGY

The Toaster has way too much available power, so a simple on/off control would not be ideal. Although mostly resistive, the heaters have some inductance that would generate quite intense noise if activated outside the zero-crossings. To solve these two possible problems, the activation is performed right after the zero-crossing detection, and some cycles are "skipped" to control the available power (think of it as the system's "gain") at each stage of the soldering process. Preheating and soaking do not need much power, but soldering needs all the power available to make the profile close to the ideal. Photo 3a and Photo 3b show the scope traces for the zero crossings (yellow trace) and TRIAC activation signal. The TRIAC gate is activated at a maximum 100-µs delay from the zero-crossing, and the software keeps it active for at least 2 ms to ensure that the TRIAC has enough current flowing to keep it on through the entire semi-cycle. The examples are, respectively, two cycles out of six and four cycles out of six.

SOFTWARE

The Keil IDE and Luminary driver library shortened the learning curve. I

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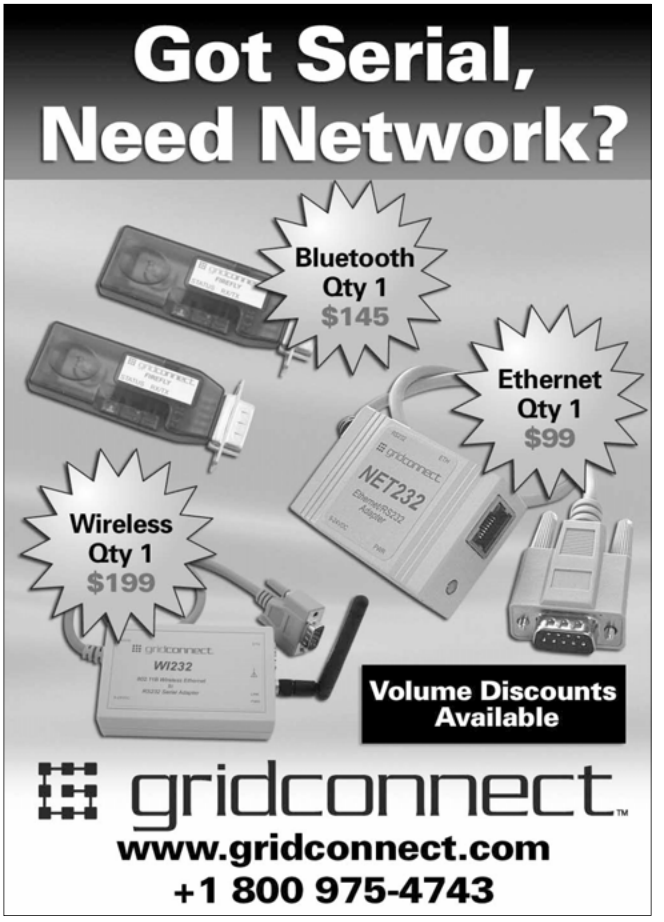

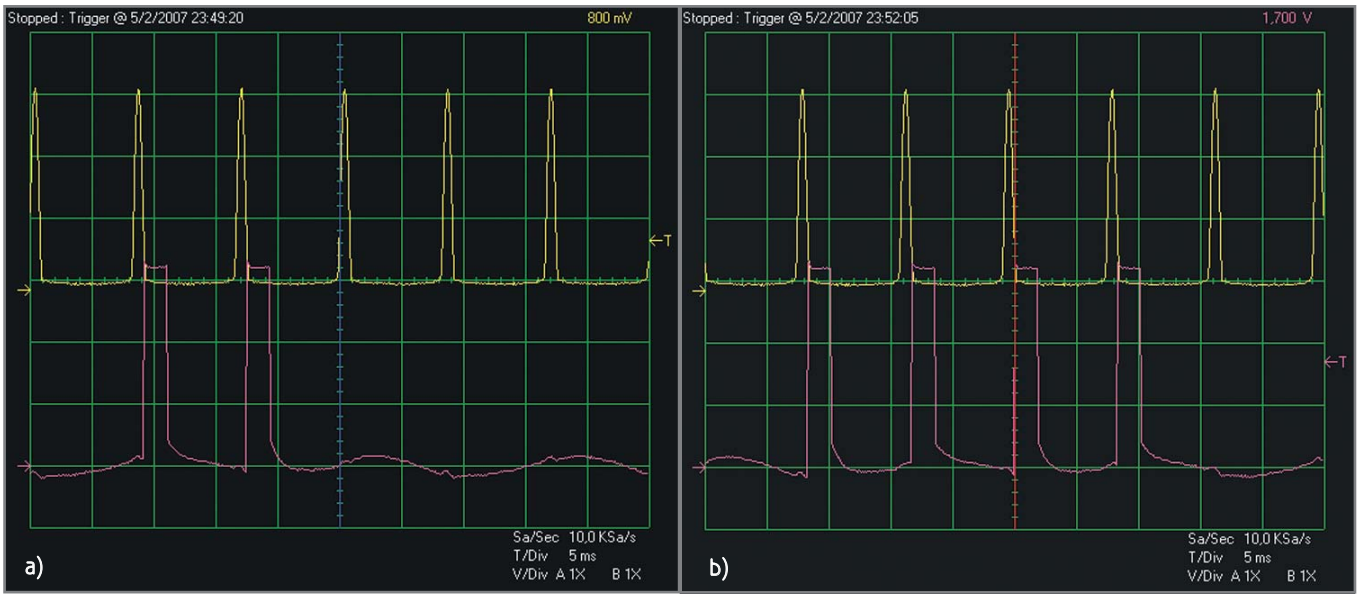

Photo 3a—Zero-crossings are in yellow. This example is two cycles out of six. Triac activation is in purple. **b**—Zero-crossings are in yellow. This example is four cycles out of six. Triac activation is in purple.

had my first "Hello World" program running in less than an hour! It was easy to use, and there were plenty of "CPU cycles" available. As a result, I could use C language exclusively, and I didn't have to worry about exhausting the available resources—as we do most of the time when using 8-bit parts.

All the program's time-critical functions occur inside timer interrupts. The main loop handles decisions that are made every 0.25 s and user interfacing. The pulse-skipping TRIAC activation and zero-crossing control is all done inside a 100-µs interrupt.

I also developed a Delphi 3—yes, I am that old!—program to make it easier to visualize the reflow profile performance.

It's not the main topic in this article, but it's important enough for at least a paragraph! Why would I use something as old as Delphi 3 instead of the richer languages that are currently available? Simple: it gets the job done and I know how to use it quite well. I choose the tools I use with great care, which means I always try to use the most effective tools without worrying whether they are outdated or unfashionable. My main concern is always to deliver the best product for the given budget and time I'm allotted.

FIRMWARE

The firmware includes three sections. The main loop section takes care of the temperature profile, serial output of process data, display output, and checking for button presses. The second section includes the LCD control functions. The third section includes the timer interrupts that control the heater's activation according to the "parameters" determined by the main loop.

By putting time-critical procedures in the timer interrupt handlers, the main program becomes much simpler and less time-critical. Once the interrupts are debugged, you can forget about how the heaters are controlled. You just "say" how you want the temperature to be in the main loop and it just "gets done." Debugging interrupt routines can be troublesome; but in many projects (like this one), they make life much easier. If you're a disciplined coder who remembers that any data that may be used inside interrupts needs to be handled in an atomic way, and that operations inside an interrupt routine need to be "fast-paced," it is not a big deal. State machines are a great way to code algorithms inside interrupt routines.

I could have stored the temperature profile in an array, but I just left it hard-coded. As far as I could see, the only situation that could require a change in the profile parameters would involve using the same controller on a larger toaster—and if that ever happens, I can just recompile the program with new

Listing 1—Simple software controls TRIAC driving.

```
//*****************************************************************************
// The interrupt handler for the timer interrupt that controls triac driving
//*****************************************************************************
void Timer0IntHandler(void)
{
    TimerIntClear(TIMER0_BASE, TIMER_TIMA_TIMEOUT); // Clear pending Interrupt signal

    // During the zero crossing do not do anything, wait for it to end
    // The zero crossing pulse takes about 800 us

    if ((GPIOPinRead(GPIO_PORTC_BASE, Zcross)))    // Test if inside zero crossing
    {
        ZcrossActive = 1 ;
    }
    else
    {
        // Counts Zero Crossings for the pulse skipping
        if (ZcrossActive)     // Executes once at the end of the zero crossing pulse
        {
            ZcrossActive = 0 ;              // Prepares for next zero crossing
            ZcrossCount++ ;                 // Increments Cycles
            if (ZcrossCount > 4)            // If 5 zero counter
        ZcrossCount = 0 ;
            TriacOnTimer = 0 ;              // Triac is not fired yet
        }
        if (ToasterOn)                      // If control wants more heat
        {
            if (ZcrossCount < OnCycles)     // Activates for OnCycles, limits
        {                                   // power at each stage
                                            // by skipping AC cycles
            TriacOnTimer++ ;
            if (TriacOnTimer < 20)          // Turn on the triac gate for 2 ms
                GPIOPinWrite(GPIO_PORTC_BASE, Out1, 0) ;      // Turn on the heater
            else
                GPIOPinWrite(GPIO_PORTC_BASE, Out1, Out1) ;   // Off gate current
            }
    }
    else
    {
            GPIOPinWrite(GPIO_PORTC_BASE, Out1, Out1) ;       // Turn off the heater
    }

 }

}
```

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parameters. The software is simple and gets the job done (see Listing 1). As engineers, we should always try to get a job done as cheaply as possible while still respecting safety requirements and performance specs. Code aesthetics should not be your main concern.

The LCD controller does not have a character generator, so I made a RAM buffer for the entire display and "downloaded" the changes to the LCD controller once for each 250-ms main loop cycle. There is plenty of time to spare while the CPU is just waiting for the next temperature reading. Keeping the buffer in RAM makes it easy to mix text and graphics on the display.

Serial output uses the routines that came with the Keil examples and just output characters. This can be done without interrupts, but I left the full interrupt support just in case it becomes necessary in the future. Plenty of resources are available, so there's no need to worry about a little more code or RAM usage.

The timer interrupt that controls heater activation is the most interesting part of the program. It is simple and gets most of the job done with minimal intervention from the main program. It counts the zero-crossings and activates the TRIAC gate at the right moment for the number of cycles that are best for each stage of the temperature profile. It keeps the TRIAC gate active for enough time to ensure it has sufficient current flowing to stay on for the rest of the cycle. This also helps to keep TRIAC heat to the lowest possible levels.

The user input interface is just a button that restarts the timers and counters for the soldering process. It couldn't get any simpler than that!

The display output shows all the important soldering parameters at each soldering stage and a graph of the temperature. The temperature graph overlaps itself a few times to show the profile with enough resolution in the available display space. The output is particularly important when you have an expensive prototype inside the toaster! It's essential to keep an eye on the process.

ART & SCIENCE

Engineering is both an art and a science. Why can't it be fun? It can be and should be—especially if we are to get the job done with the tight budgets and impossible schedules that we manage everyday! I can still remember my first blinking LED with a transistor multivibrator running on a protoboard! Today, I get the same thrill at my "day job," but it's even more exciting when I complete a project after hours. I love seeing a nicely soldered board come out of my toaster!

The results of this "proof of concept" project couldn't be much better! The cost to develop the project was minimal. The temperature profile is as good as a larger, more expensive reflow oven. Plus the process information is always available via the graphical display. As a result, boards come out nicely soldered in a few minutes. The pleasure of doing something in a new way is simply priceless.

Alexandre Ney Guimarães (alexandre@logikos.com.br) is the CTO and founder of Logikos Tecnologia. He has worked as an embedded hardware and firmware designer for more than 20 years, during which time he worked on projects ranging from bathtub controllers to a full audiometer design. At the age of 12, he began experimenting with blinking LEDs and making weird noises with speakers and astable multivibrators. Alexandre's passion for electronics and computers bloomed during his high school years. Although he considers himself self-taught, Alexandre has studied electrical engineering on and off at PUC-Rio College in Brazil.

PROJECT FILES

To download the code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2010/237.

SOURCES

R276 Solder paste
Kester | www.kester.com

MAX6675 Thermocouple interface
Maxim Integrated Products | www.maxim-ic.com

PCD8544 LCD Controller
NXP Semiconductors | www.nxp.com

Type K Thermocouple
Omega Engineering | www.omega.com

CP2103 Serial-to-USB interface
Silicon Laboratories | www.silabs.com

LM3S102 Microcontroller
Texas Instruments, Inc. | www.ti.com

NEED-TO-KNOW INFO

Knowledge is power. In the computer applications industry, informed engineers and programmers don't just survive, they *thrive* and *excel*.

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—

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by Ed Nisley

Totally Featureless Clock (Part 2)

Hardware

The first part of this series about a "totally featureless clock" detailed how to build a WWVB simulator. This article covers the clock's hardware and overall design.

My friend's Totally Featureless Clock, which *simply* displays the current hour and minute, seemed like it should be a *simple* project. After all, keeping time is a *simple* matter of addition: add 1 to the current time each minute. Right?

It's somewhat more complex than that, of course, but much of the complexity lies in the analog and signal processing parts of the project. In this column, I'll describe the clock's overall design and the hardware part of the project. My next column will cover the firmware, including how it determines signal quality and synchs with WWVB, plus the error handling required to ensure the clock always displays the correct time.

BEHIND THE BLUE DIGITS

The clock sets itself from WWVB as often as possible and free-runs whenever RF conditions prevent signal reception with acceptable quality. It shows an error indication when its internal time may have drifted far enough from WWVB's value to affect the display. As far as my friend is concerned, the clock requires no adjustments whatsoever.

Photo 1 shows the "user interface" side of the Hour board during construction on my workbench. I use CadSoft's EAGLE schematic and PCB layout editor, which limits the maximum PCB to 160 × 100 mm, so I divided the clock into its two natural pieces, with a column of short jumpers linking the Hour and Minute boards.

The two boards fit inside a bezel barely larger than the board outline, behind a neutral density filter to improve display contrast and reduce the overall brightness. From the front, a simple black rectangle showcases four blue digits and a colon: there's not much to it. I used telescoping brass tubing and translucent plastic diffusers to shape the discrete LEDs into sharp-edged dots.

The back of the Hour board, shown in Photo 2, has an Arduino Pro microcontroller plugged into header strips straddling the power supply

Photo 1—The front of the Hour board holds two 76-mm blue LED digits (with their protective film still in place), two discrete LEDs forming a colon, and a large CdS photoresistor to sense room illumination. The finished housing puts a dark neutral density filter in front of the entire display to improve contrast.

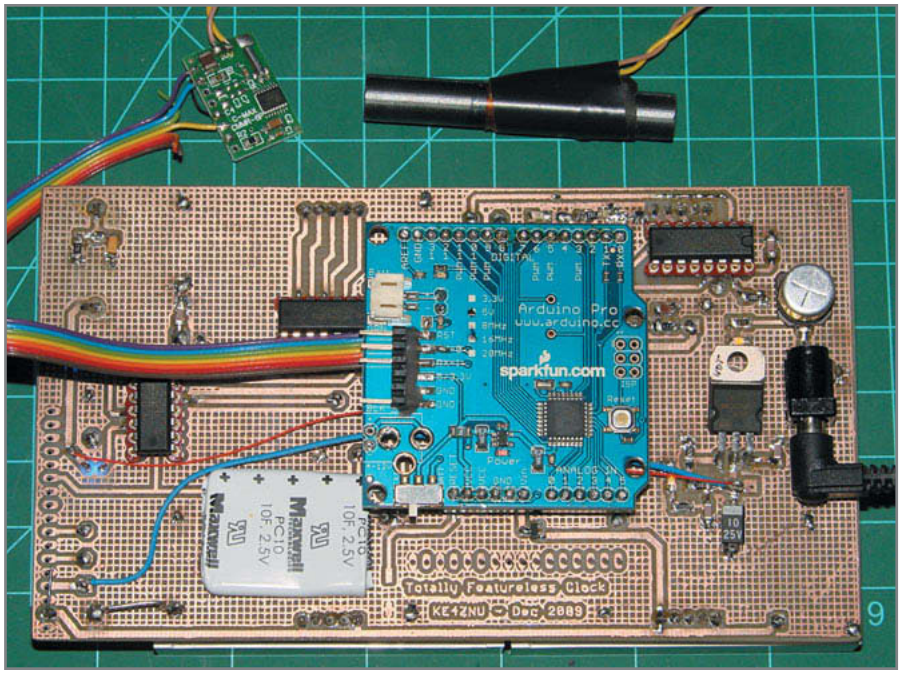

Photo 2—The circuitry side of the Hour board contains most of the clock hardware: the ultracapacitor power backup, LED drivers, and an Arduino Pro microcontroller. The Minute board connects to the column of pads along the left side. The C-MAX WWVB receiver and bar antenna mount on the Minutes board.

and display drivers. The small board on the ribbon cable is the C-Max CMMR-6P-60 WWVB receiver, also connected to its ferrite bar antenna. The Minute board, which I won't describe in detail, consists of just two display drivers, DIP configuration switches, and a shielded area for the WWVB receiver.

You can see that the clock has an extremely simple hardware design. Because I know who will be using this clock and we agreed on exactly what it should (and should not!) do, there's no need for buttons, knobs, and other user-interface frippery. A commercial clock requires those features: this isn't a mass-market design.

The firmware is considerably more complex. It converts the WWVB receiver's output into pulse-width measurements, error-checks the signal's format, parses valid time codes into the numeric values that determine the current UTC time, and synchronizes its variables to that time code. Those variables tick along under control of a timer driven by the microcontroller's clock oscillator, with the firmware adjusting the countdown ratio to correct the oscillator's frequency offset and drift. The firmware converts UTC time from its variables to local time, then to the LED segment patterns, and sends those bits to the display drivers.

That's all there is to it!

REDUCING THE NOISE

Most large LED displays use multiplexing, activating only one digit or segment of each digit at any time. Multiplexing simplifies the hardware and improves power efficiency, at the cost of high-speed, high-current switching. The highest current will be roughly (number of digits) × (LED peak current rating), more than 3 A for this clock. Putting a sensitive radio receiver beside that circuitry simply begs for trouble.

I avoided those problems with a simple direct-current display design: four Texas Instruments TLC5916 drivers draw a constant current through each illuminated segment. The schematic in Figure 1 shows the connections on the Hour board; the Minute board is similar. DC drive has the pleasant side effect that the digits don't flicker or break up during sudden eye movements, which both my friend and I find unpleasant.

An 8-bit register inside each TLC5916 controls the display current, although the current does not vary linearly or even monotonically with the register value. An external resistor determines the maximum current; the chip can handle 120 mA per output, far in excess of the 20 mA limit for these digits. The dynamic range is, unfortunately, fairly small: 1.58 to 18.8 mA for the 1-kΩ resistor I used, just over 10 dB.

The Arduino Pro controls the TLC5916 chips through its hardware-assisted SPI interface pins, using the same technique I described in my

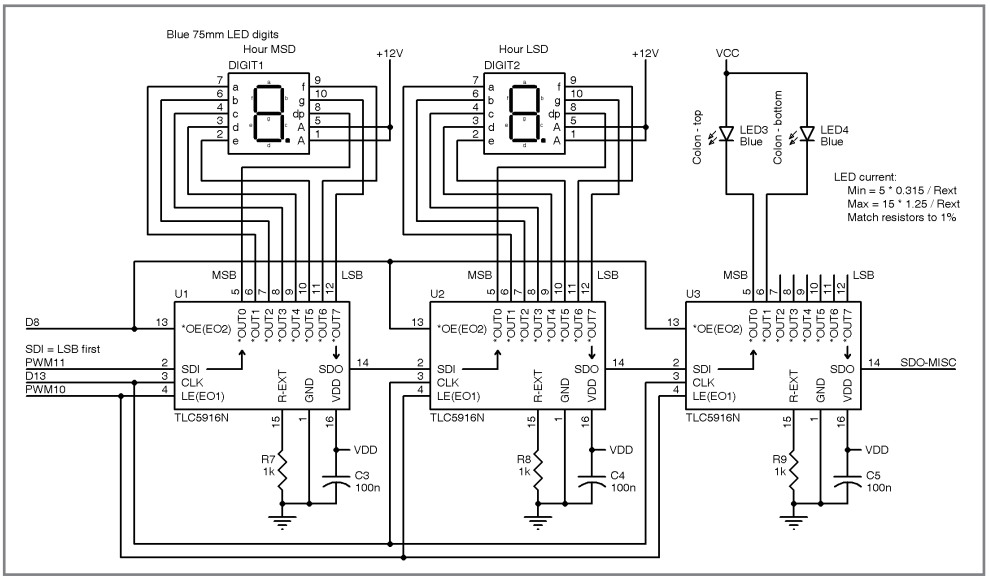

Figure 1—The TLC5916 drivers maintain a constant direct current in each LED display segment. Two discrete LEDs form the colon, with each LED under program control.

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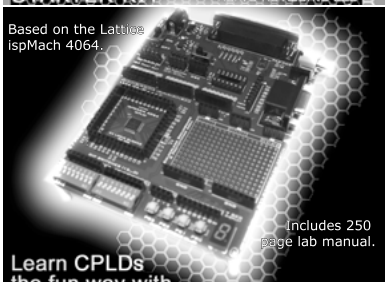
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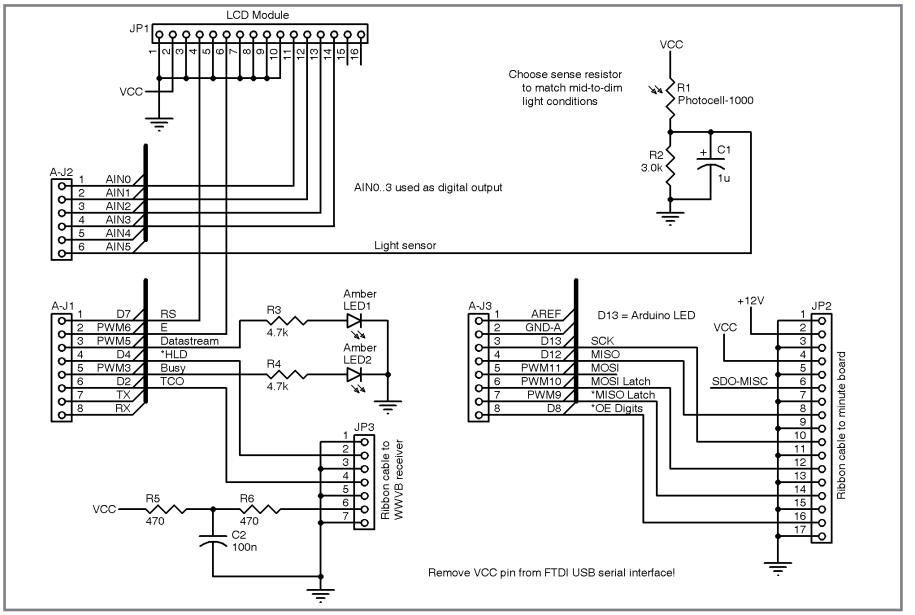


Figure 2—An Arduino Pro microcontroller handles all the logic, with one input bit from the WWVB receiver, an analog input from the photoresistor, and an SPI chain to the display drivers. Photo 2 shows that the LCD interface isn't used.

December 2009 column about the Tektronix memory reader board. Figure 2 shows the microcontroller connections: three SPI pins and one display-enable bit under software control.

I set the SPI interface to 250 kbps, equal to the CPU clock oscillator frequency divided by 64, which is a reasonable compromise between high speed and simple wiring. Each display update requires 5 bytes, just over 160 µs, so the serial interface has no effect on performance. The clock sets the time and display brightness every 4 seconds, spending essentially all of its time waiting.

The WWVB receiver has an input that freezes its Automatic Gain Control setting, which is generally used in environments with occasional high-intensity RFI: freezing the AGC prevents noise burst from swamping the WWVB signal. In this application, however, the microcontroller and display run full-time, so they must be quiet enough (or well-shielded enough) to prevent interference with the AGC active.

TURNING DOWN THE LIGHT

My friend says all her LED clocks are far too bright and she most emphatically did not want a brilliant display that lit up the entire house at night. I decided to set the LED current to correspond with room illumination, turning it down as far as possible overnight.

The photoresistor shown in the upper-right corner of Photo 1 and Figure 2 provides a way to measure room illumination. The LED digits leak a surprising amount of light through their white-plastic sides, so I put a brass shroud around the photocell to limit its view. The front face of the clock consists of a single layer of 1-stop neutral-density filter; the shroud fits through holes in the additional layers of 2-stop filter material that permanently reduce the maximum display brightness.

The firmware reads the voltage across the photoresistor every 4 seconds, combines that value with the average of 15 previous measurements to eliminate sudden changes, then sends the appropriate current-control command to the TLC5916s.

Unfortunately, the driver's 10-dB current range is far less than the possible variation in room brightness. The photoresistor varies from about 50 Ω in full sunlight to 500 kΩ in total darkness, a 40-dB range, although typical room illumination falls in a 10-dB range near 1 to 10 kΩ.

The firmware tracks the minimum and maximum illumination levels and maps the LED current range across those extremes, so a dark room will always receive the minimum LED light. This isn't ideal, but it seems to work well in practice. The firmware slowly pushes

the minimum and maximum values toward the average to ensure that they don't get stuck at transient extremes.

POWER CONTROL

Each digit segment contains four blue LED chips wired in series, so the displays run at a nominal 11 to 12 VDC. I used an unregulated 12-VDC, 1.2-A wall wart that produces about 13.5 V under a typical load. That's enough voltage headroom for the TLC5916 constant-current drivers to maintain proper regulation. The entire clock dissipates 5 W (mostly in the LED panels!) while showing 12:08 to a bright room, so this is not a low-power project.

There is, obviously, no practical way to provide enough battery backup to keep the LEDs lit during even a short power failure. Instead, I put a pair of Maxwell 10 F ultracapacitors in series across the Arduino Pro's V_{CC} supply to support just the microcontroller during power outages. This brute-force solution, enabled by recent capacitor development, eliminates all the tricky power-management programming.

The capacitors have a 2.5 V working voltage. Stacking two in series halves the total capacitance, but they still have far more energy storage than any ordinary electrolytic cap that would fit in the clock's ruthlessly flat package.

The capacitor specs set a maximum self-discharge current of 40 µA, which corresponds to a leakage resistance of about 60 kΩ at 2.5 V. That's not a tightly controlled value, so you must add balancing resistors across the capacitors to equalize their terminal voltages. I measured the self-discharge resistance at about 100 kΩ and used 10-kΩ resistors that draw about 250 µA. The capacitor voltages remain within 100 mV of their rating through the entire charge-discharge cycle.

The Arduino Pro draws about 30 mA at 5 V and somewhat less at 3 V, so a 5 F capacitor can hold V_{CC} above the 2.7 V brownout reset level for more than 6 minutes.

$$6.4\ \text{min} = \frac{5\text{F} \times (5 - 2.7)\text{V}}{60\ \text{s} \times 30\ \text{mA}}$$

A lithium cell could provide a much longer runtime, but at the cost of charging circuitry for a secondary cell or replacing a dead primary cell after each outage. My friend reports that the utility power to her house fails for only a few minutes at a time, a few times a year, and she's willing to use her watch until the clock recovers by itself.

The LM317 regulator in Figure 3 supplies 5 V for the circuitry on the clock board and charges the ultracapacitors through a Schottky diode and 510-Ω limiting resistor. The charging time constant is astonishing:

$$2550\ \text{s} = 510\ \Omega \times 5\ \text{F}$$

A full charge therefore requires more than 2 hours, which is reasonable in

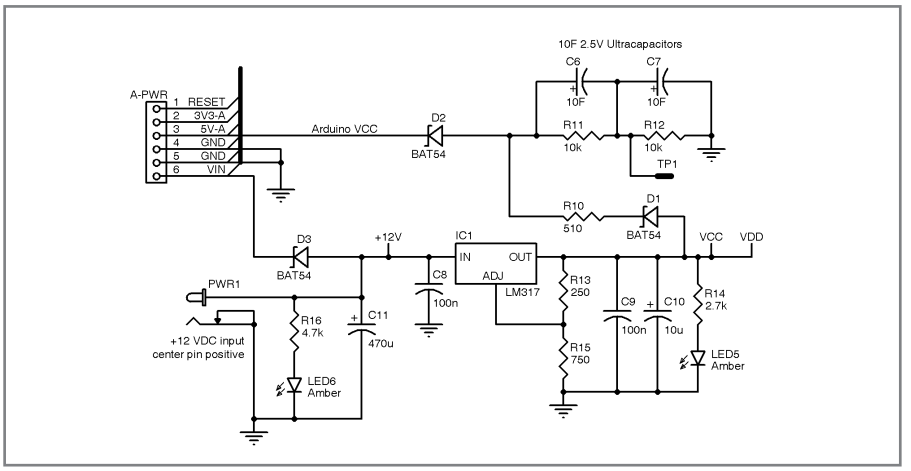
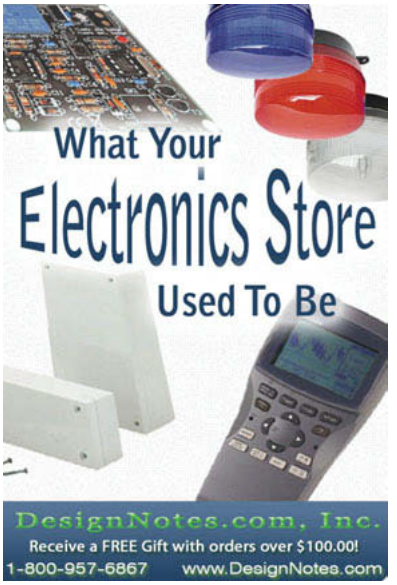
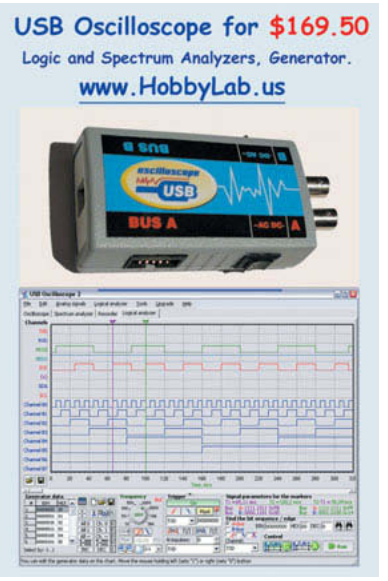
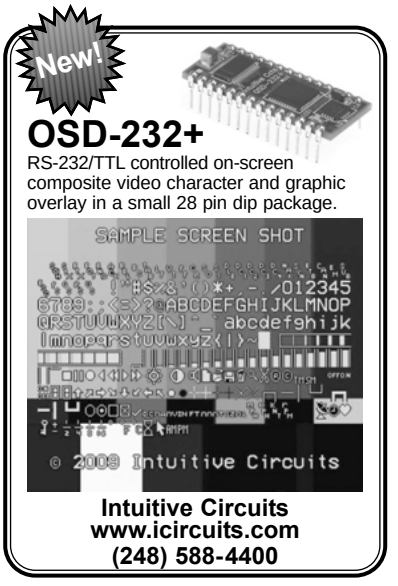
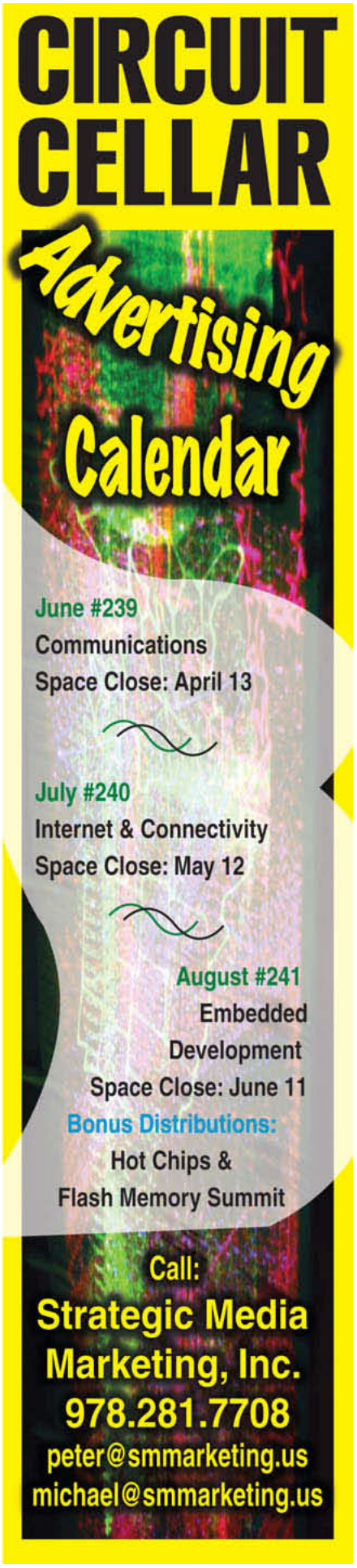


Figure 3—A 12-VDC wall wart supplies power: the LED displays dissipate nearly 6 W. The 10 F ultracapacitors support the Arduino microcontroller's VCC during power failures; the rest of the circuitry goes dark.










```
WWVB: 09834909 Flags=0510  Valid 1
Set: 09 349 20:09:59.9 Loc= 3 Age=0       LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=15

UTC: 09 349 22:44:00.9 Loc= 5 Age=138   LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=15
WWVB: 448B4909 Flags=0510  Valid 1
Drift: Elapsed 8280 Offset -33 Correction -159 ICR1 39840
Set: 09 349 22:44:59.9 Loc= 5 Age=0       LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=15

UTC: 09 350 00:59:00.9 Loc= 7 Age=130   LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=16
WWVB: 58035009 Flags=0510  Valid 1
Drift: Elapsed 7740 Offset 0 Correction +0 ICR1 39840
Set: 09 350 00:58:59.9 Loc= 7 Age=0       LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=16

UTC: 09 350 02:32:00.9 Loc= 9 Age=93     LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=16
WWVB: 320B5009 Flags=0510  Valid 1
Drift: Elapsed 5580 Offset -1 Correction -7 ICR1 39833
Set: 09 350 02:32:59.9 Loc= 9 Age=0       LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=16

UTC: 09 350 04:38:00.0 Loc=11 Age=126  LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=16
WWVB: 37135009 Flags=0510  Valid 1
Drift: Elapsed 7500 Offset 1 Correction +5 ICR1 39838
Set: 09 350 04:37:59.9 Loc=11 Age=0       LY=0 LS=0 DST=0 Chg=0 UT1=1 Mon=12 DOM=16
```

Figure 4—The WWVB time code establishes the exact interval between two clock settings. Comparing that with the same interval measured by the local oscillator reveals the oscillator's frequency error. These lines show several successive frequency adjustments that reduce the oscillator's error from 0.4% to under 0.02%.

this always-on application. The three Schottky diodes in Figure 3 prevent the Arduino board and the ultracapacitors from powering the clock circuitry during outages.

It's worth noting that the entire collection of digital logic draws less current from the power supply than two segments of the LED display. Although LEDs win any energy efficiency contest with incandescent bulbs, they use nearly all of the power in this circuit!

TWEAKING THE TIMEBASE

Because the WWVB signal fades into the ambient noise during most of the daylight hours, the Totally Featureless Clock must also function as an independent clock. All clocks have an oscillator to measure time and, alas, all oscillators have some inherent error.

The Arduino Pro microcontroller board generates its clock from a 16-MHz ceramic resonator, rather than the more typical quartz crystal. Resonators make poor clock oscillators, with a typical frequency accuracy of ±0.5%, while a bad quartz crystal might be off by only ±0.01%.

Both numbers seem small, but half a percent adds up to 432 seconds over 24 hours: more than 7 minutes. That's large enough to be obvious, even on a clock displaying only hours and minutes, and far more than my friend was willing to accept.

A WWVB-based clock has a major advantage over a completely free-running clock: it knows the exact time, at least occasionally. Two observations can compensate for the local oscillator's frequency offset, while continuing observations can track and correct the effects of temperature and aging.

Figure 4 shows the clock's diagnostic output for six successive WWVB synchronizations, starting with the first synch after a hardware reset that set the clock's internal time. The next synch occurred *exactly* 138 minutes later, as computed from the WWVB time codes, but the local variables showed 33 seconds less time had elapsed.

That offset means the local oscillator was running slow by:

$$0.4\% = 3.99 \times 10^{-3} = \frac{33}{8280}$$

Although I don't know the exact spec for the Arduino Pro resonator, the observed frequency error is within the usual specification.

I set the Atmel ATmega168's `Timer1` clock prescaler to 8, which ticks `Timer1` at 2 MHz, then divided that by 40,000

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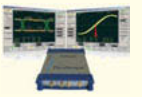

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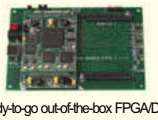

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to get a 50-Hz interrupt frequency. Changing the `Timer1` period by one tick changes the frequency by:

$$0.0025\% = 25 \times 10^{-6} = \frac{1}{40 \times 10^{3}}$$

The firmware computes the error, multiplies by the current `Timer1` period, then adjusts the period by that amount. The `Drift` lines in Figure 4 summarize those computations.

The first 0.4% correction subtracted 159 counts from the `Timer1` period, adjusting the error below 1 second (which truncates to zero) during the next 130 minutes. The time was off by 1 second in the next 93 minutes, reducing the period by another 7 counts.

After 126 minutes the local clock was fast by 1 second and the longer baseline reduced the adjustment to +5 counts. The error correction seems to be tracking the oscillator's temperature drift.

The resonator stabilized during the course of two continuous power-on months and now keeps time to within 2 seconds in 24 hours. That's the smallest adjustment possible: 1 part in 40×10^3. The firmware now steps ICR1 by one count around 39841, the value that sets the Timer1 period to exactly 20 ms, with a change perhaps every other day.

CONTACT RELEASE

With the hardware in hand, a touch of firmware can now convert it into an actual clock; that's next column's topic.

The row of empty holes near the front of the circuit board is for an ordinary 44780-based LCD module. Although my firmware doesn't use an LCD, you could build a fine WWVB clock without the inordinate power drain of those big LED digits. You can download the complete source code, schematics, and PCB layout from the *Circuit Cellar* FTP site.

Ed Nisley is an EE and author in Poughkeepsie, NY. Contact him at ed.nisley@ieee.org with "Circuit Cellar" in the subject to avoid spam filters.

PROJECT FILES

To download the code, schematics, and PCB layout, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2010/237.

RESOURCES

M. Lombardi, et al., "WWVB Radio Controlled Clocks: Recommended Practices for Manufacturers and Consumers," Special Publication 960-14, NIST, 2005, http://tf.nist.gov/general/pdf/1976.pdf.

S. Nickels, "Time Server Design: Synchronize with the WWVB Time Code Signal," *Circuit Cellar* 220, 2008.

E. Nisley, "Totally Featureless WWVB Clock (Part 1): WWVB Simulator," *Circuit Cellar* 235, 2010.

NIST, WWVB transmitter and data format specs, www.tf.nist.gov/stations/wwvb.htm.

SOURCES

Arduino Pro Microcontroller board
www.arduino.cc/en/Main/ArduinoBoardPro

EAGLE Schematic and PCB layout
CadSoft | www.cadsoftusa.com

CMMR-6P-60 WWVB Receiver (Digi-Key Part No. 561-1014-ND)
C-MAX | www.c-max-time.com
Digi-Key Corp. (distributor) | www.digikey.com

76-mm Seven-segment blue common-anode LED digits
eBay, Inc. | www.ebay.com

Neutral density filters
LEE Filters | www.leefiltersusa.com

PC10 Ultracapacitors
Maxwell Technologies | www.maxwell.com/ultracapacitors/products/small-cell/pc-10.asp

TLC5916 LED Driver
Texas Instruments | www.ti.com

NEED-TO-KNOW INFO

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***Circuit Cellar* 194, 2006**

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Antenna Basics
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by Robert Lacoste

Picoammeter Design

If you occasionally work with low currents, you should have a picoammeter on your workbench. With some perseverance and a little know-how, you can build one in a couple of hours. But first you need a good understanding of current measurement and transimpedance amplifiers.

Welcome back to "The Darker Side." I think I got my first multimeter when I was 10 years old. Well, more precisely, I took my father's multimeter and played with it so long that we soon both considered it mine. The ohm-meter feature was particularly fascinating. I could put the two wires on anything and then check the galvanometer to see if it was behaving more or less as a conductive surface. Another interesting game involved taking a wire in each hand and tightening them between two fingers to get the lowest possible resistance.

I am a little older now, but I am still playing with resistance and current measurements, even though galvanometers have disappeared from our multimeters. As you may have noticed, energy saving is a hot topic, and we can now find integrated circuits with standby currents in the tens of nanoamps range or even lower. But measuring these currents is nearly impossible with a standard multimeter. For example, my trusted Fluke 189—which is a very high-end device—has a best-case resolution of 10 nA per count, which makes measurements under 40 or 50 nA unrealistic. To measure lower currents, a dedicated low-current piece of equipment is required—namely, a picoammeter. Usually, when you work with low currents, you don't need a top-range accuracy because there are plenty other error and noise sources. But a wide dynamic range is fundamental. Moreover, you'll probably use it only a few times per year, so a homemade solution makes sense.

This month, I'll begin by covering concepts relating to current measurement and transimpedance amplifiers. I will then describe how I prototyped a small low-cost picoammeter in a couple of hours with satisfactory results. Lastly, with memories from my childhood fresh in my mind, I'll show you how I've used it to measure high impedances.

Let's go. Switch on your soldering iron.

BASIC CURRENT MEASUREMENT

Imagine that you have a wire in which a small current is circulating—say, from pico-amperes to micro-amperes. How can you measure this current?

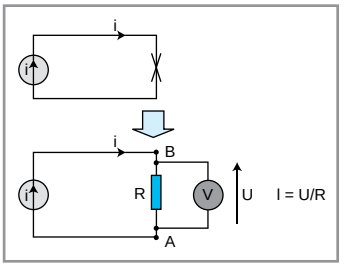

Figure 1—This is the basic current measurement method. Just open the circuit, insert a resistor, and measure the voltage across this resistor.

Some methods don't require you to open a circuit (e.g., like Hall effect sensors or current transformers), but they are usually not applicable to such low currents. You can also use a galvanometer, in which the current directly moves the indicator, but you also will be limited to reasonably high currents, micro-amperes or more. So, the most obvious and common solution is

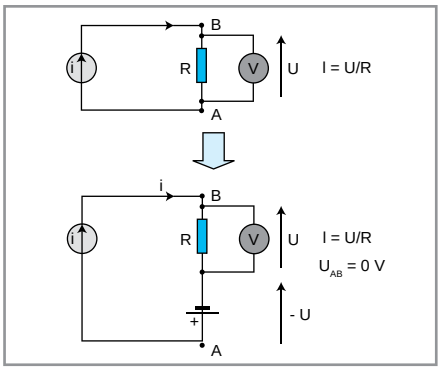

Figure 2—Unfortunately, the current moving through the circuit will be modified by the added serial voltage. The key idea is to add a counter-voltage to exactly nullify the voltage between points A and B.

to build a current-to-voltage converter followed by a high-impedance voltmeter. And the most basic current-to-voltage converter is simply a resistor (see Figure 1). Thanks to Ohm's law, the voltage across the resistor R will be $V = R \times I$, so $I = V/R$. You know R because you chose the resistor. You measure V so you can calculate I.

But this approach has two drawbacks when measuring very low currents. One, you need to use a high-value resistance. For example, if you want to convert a 100-pA current into 10 mV, you need a 100-MΩ resistor. You then need to use a voltmeter with an input impedance far higher than 100 MΩ, which will be a challenge if even possible. The other problem is more insidious: low currents are often generated by low voltages. The additional measurement resistor adds a small voltage in series on the circuit—and, of course, it's identical to the voltage sent to the multimeter. Unfortunately, this added serial voltage may change the current actually circulating in the wire. Do you want a numerical example? Imagine that the 100-pA current source is generated by a 20-mV voltage in series with a 200-MΩ resistance. If you add a 100-MΩ measurement resistance, you will change the actual current by up to 33% because the current now will be:

$$I = \frac{U}{R} = \frac{20\ \text{mV}}{(100 + 200\ \text{M}\Omega)} = 67\ \text{pA}$$

How can you get a precise current measurement without interfering with the source? You need to avoid any added series voltage. More precisely, you will insert a measurement circuit in the current loop, but the voltage between the two measurement points must stay as close as possible to zero. The solution is simple but powerful: you can add to the circuit an anti-voltage source that's set to exactly compensate the voltage drop caused by the measuring resistor (see Figure 2). That way the voltage across the measuring device stays zero as the resistor drops and the voltage source cancel each other, so a precise current can be measured. The only difficulty is that this anti-voltage must be adjusted depending on the current: if the current is constant, you can trim it yourself. But if it is varying, you need some kind of control loop to automatically adjust it.

TRANSIMPEDANCE AMPLIFIERS

If you think "op-amp" when you read the words *control loop*, you're right. A transimpedance amplifier is the exact implementation of the anti-voltage current measurement idea. Look at Figure 3. The op-amp's two inputs are connected to the two ends of the measuring device. As you know, such an amplifier, when properly wired (with a negative feedback), changes the voltage on its output until the voltages on its two inputs are identical. By the way, this is partially wrong as the gain of the amplifier is not infinite. But let's consider it to be large enough. Op-amp details will require another article.

So, at equilibrium, the voltage between points A and B is zero, which is exactly what you are looking for to avoid any perturbation on the current source. If you consider the amplifier to be perfect, no current is circulating through its inputs. Thus, the current I is entirely circulating in the resistor R and through the amplifier's output. As a result, the voltage at its output is $(-R \times I)$. This is a transimpedance amplifier: the current-to-voltage conversion ratio is identical to a simple resistor of R ohms, but with two key advantages: no added serial voltage and a low output impedance.

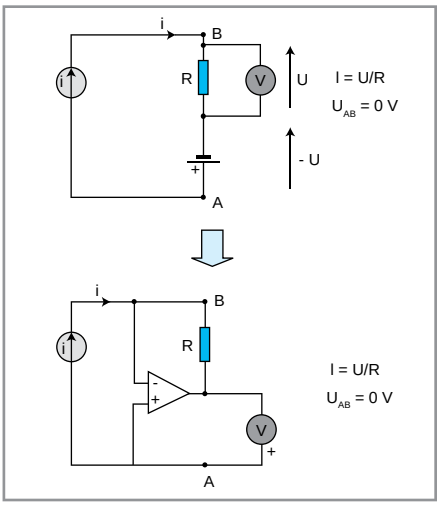

Figure 3—The transimpedance amplifier is a way to automatically adjust the counter voltage. An operational amplifier will set its output in order to have a nearly null voltage offset between its two inputs: $U_{AB} = 0$, which is exactly what we are looking for.

Of course, this presentation of transimpedance amplifiers was a little simplistic. Perfect op-amps are difficult to find, so you will have to select a device with reasonably low input offset voltages and high enough input impedance (meaning far higher than R). Usually, you will also need both positive and negative power supplies for the amplifier because its output will be below 0 V when the input current is positive.

Figure 4 depicts you a simulation of a transimpedance amplifier performed with Labcenter's VSM software. The virtual voltmeter shows you the simulator output voltage of the op-amp.

Transimpedance amplifiers are everywhere. In particular, I bet that you will find them in most photodiode-based designs, as such a light sensor generates low currents with low voltages. By the way, another advantage

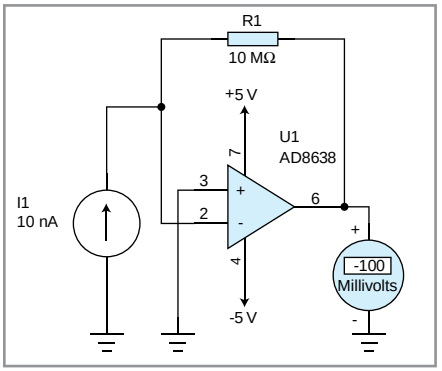

Figure 4—This is a simulation of a transimpedance amplifier done under VSM. The input current of 10 nA is translated into a –100-mV voltage thanks to the 10-MΩ feedback resistor.

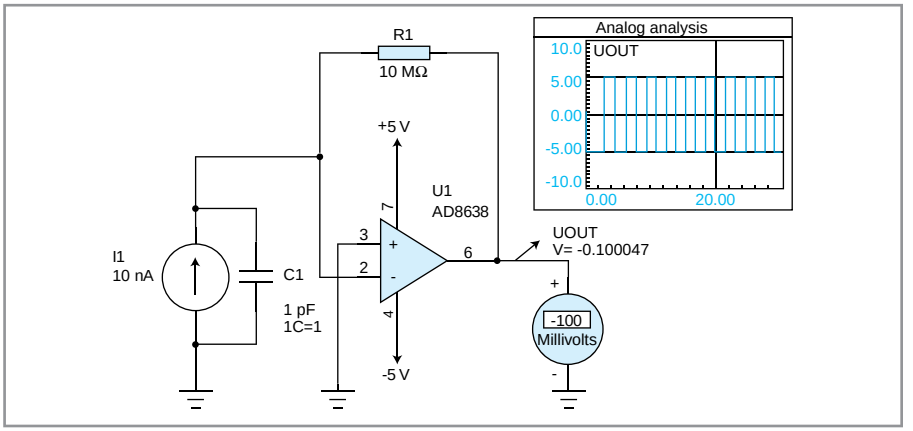

Figure 5—If you consider that the input source has a parasitic parallel capacitance, and if you don't damp the amplifier with a capacitor in parallel to the feedback resistor, then you will have unfortunately built an oscillator, as demonstrated here.

of the transimpedance amplifier over a simple series resistor is speed. Why? Imagine that you build an optical data transmission system with a photodiode providing a 100-nA current. No component is perfect, so this photodiode will also have a parasitic parallel capacitance, usually around 10 pF. Imagine that you measure this current with a simple high-value resistor—say, 100 kΩ—to get a 10-mV output. What will happen? The 10-pF capacitor and this 100-kΩ resistor will implement a low-pass filter with a time constant of RC = 1 µs, so the bit rate will need to stay quite low. There's no way go get significantly higher than 1 MBps. In comparison, with a transimpedance amplifier, the measuring resistor is not "visible" to the source, as the voltage at the measurement point stays at 0 V thanks to the amplifier, so the bit rate is limited only by the op-amp's bandwidth and parasitic components. Far better performance is possible, as proven by gigabits-per-second fiber links.

However, this source of parasitic capacitance induces another problem. It might transform your amplifier into an oscillator. The problem, which is simulated in Figure 5, will make your life a little more difficult when working on real-world applications. This is not the only kind of circuit where parasitic oscillations can occur, but it is always unpleasant. Fortunately, there's a solution: you can limit the bandwidth of the transimpedance amplifier by adding a parallel capacitor across the feedback resistor. Although this will slightly reduce the system's bandwidth, it will make it stable. Bob Pease provides a good explanation in his article, "What's All This Transimpedance Amplifier Stuff, Anyhow?" (*Electronic Design*, 2001). Basically, this additional capacitor should be proportional to the square root of the source capacitance and inversely proportional to the square root of the feedback resistor and gain bandwidth of the amplifier. Anyhow, you will not know the source of parasitic impedance in many applications, so you'll have to use the trial-and-error method: increase the feedback capacitor until you achieve stability, then increase it a little more, and then test it in all conditions. It should work.

BUILD A PICOAMMETER

You're now familiar with all the basic ideas associated with designing a low-cost picoammeter. Figure 6 is a full schematic diagram of my prototype. The design is quite simple, but I carefully selected the components. Starting from the two inputs, I included two protection diodes (D1 and D2), which limit input voltage to ±0.6 V to prevent overloading. Be really careful. These diodes can't be generic because their reverse current must remain far lower than the measuring range—100 pA in this instance. I used a pair of low-leakage NXP Semiconductors BAS416 diodes, which are rated at 3 pA. (Compare this value with the 25 nA of a standard 1N4148. Even at 20°C, it's nearly 10,000 times lower.) Then the transimpedance amplifier is built around an Analog Devices AD8638 op-amp, which was selected for its low offset (9 µV) and small bias current (7 pA is typical). The gain resistor is manually selected from 1 Ω to 10 MΩ with a manual rotary switch, and of course each resistor has its corresponding parallel capacitor to avoid oscillations. A second op-amp provides another 100× voltage gain, as well as offset compensation through a trimming resistor in

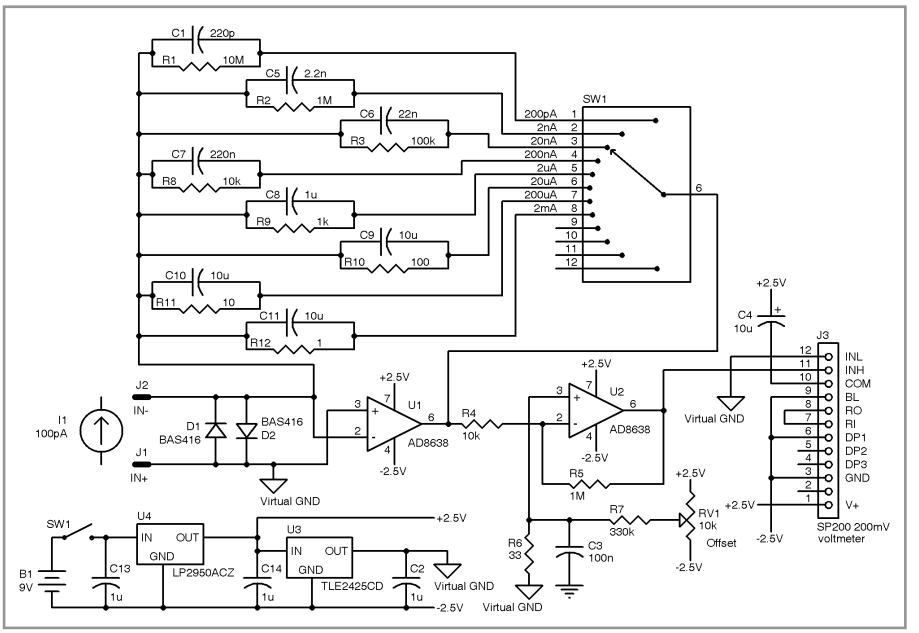

Figure 6—This is the full schematic of my small picoammeter. There are very few components except the rotary switch and its different feedback resistors and compensating capacitors.

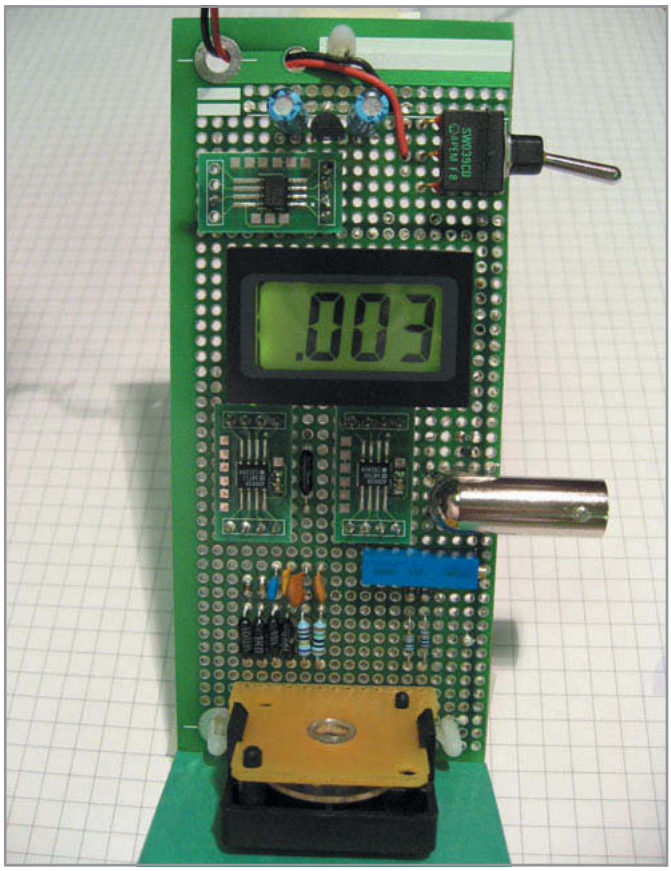

Photo 1—Even if this is usually not a good idea for such low-level signal designs, I built the ammeter on a standard prototyping board. Far better results could be achieved with a proper printed circuit board. I used precision resistors everywhere to avoid the need to calibrate the device.

order to get a 200-mV full-scale output.

For a display, I simply hooked up (at the output) a standard 3.5-digit voltmeter module (Lascar Electronics SP200), built around a MAX138 ADC. Just take care to use a meter with true differential inputs like this one.

Lastly, let's consider the power supply. I don't recommend using anything other than a battery for your picoammeter's power source. Any transformer will have huge parasitic currents in comparison to the pico-amperes you want to measure. I used a simple 9-V battery regulated by an LP2950 5-V regulator. A symmetrical power supply was needed, so I added a Texas Instruments TLE2425 virtual ground generator. This chip divides the power supply rail into two halves, so I could use its output as a virtual ground and the 0- and 5-V lines as a ±2.5-V power source.

Such a circuit must be assembled on a properly designed PCB to achieve good performance. In particular, a good ground plane should be used, as well as guards around the ultra-low-current inputs. Well, I tried to build it on a standard prototyping board (see Photo 1 and Photo 2). I expected disappointing results, but I was pleasantly surprised to be able to use it down to the 2-nA full-scale range. Honestly, the 200-pA range is currently useless because measurements are a little erratic, but it should be usable with a proper PCB. I had more difficulties with the high current ranges of 200 µA and 2 mA, which occasionally oscillate on my prototype. The feedback capacitors on these two ranges are definitively too small, but the difficulty would be to find low-leakage capacitors with high capacitance, more than 100 µF. Anyway, this is not a serious problem because my standard multimeter is working like a charm for reasonably high currents. I didn't spent a lot of time on this issue.

If you want to build this picoammeter, I'm sure you will be able to design a pretty PCB for it. Don't forget the ground plane, and remember to put it in a shielded enclosure for the best results. You can also easily replace the 3.5-digit voltmeter display with a microcontroller and a standard LCD. Doing so will enable you to add zillions of interesting features like software-based auto-zeroing (very helpful), averaging (helpful with noisy signals), or even automatic range selection through reed relays or something similar. Don't hesitate to share your design ideas with other *Circuit Cellar* readers!

Another interesting option would be to use a derivative form of the transimpedance amplifier, where the feedback resistor is replaced by a capacitor. This gives an integrator, with an integration time proportional to the input current. Dedicated chips like the IVC102 from Texas Instruments (e.g., Burr Brown) implement this concept and should be quite easy to interface with a microcontroller. And their 100-fA (yes, femtoampere) bias input current should result in impressive performances.

FIRST EXPERIMENT

Before closing, I want to describe my first experiment with my small picoammeter. I connected a 9-V battery in series with the ammeter input and built an ohmmeter, soldered a small two-pin 1-cm-wide header at the end of the wires, and pushed this homemade sensing probe on several surfaces to measure their resistance (see Photo 3). Neither a classic plastic bag nor an FR4 epoxy substrate gave measurable current, meaning lower than 10 pA. They are definitively good insulators. On the contrary, I was able to measure the resistances of a full range of other materials (see Table 1), even if nearly all the materials appeared as perfect insulators when tested with a classic multimeter. Measured values are very high, in

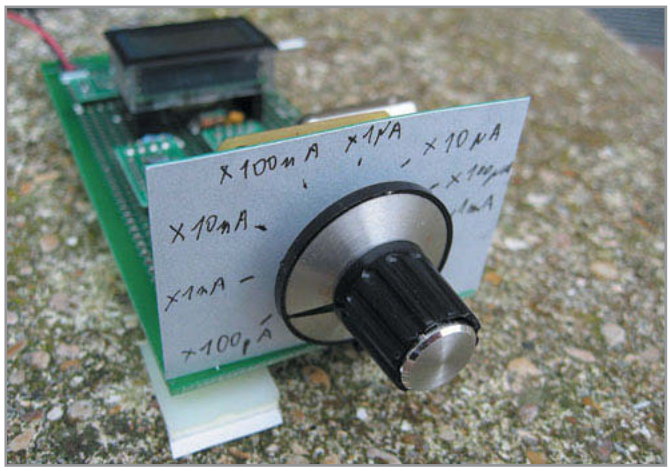

Photo 2—The legend of the range selector was, well, quickly done, but it is always impressive to see a "100-pA" range.

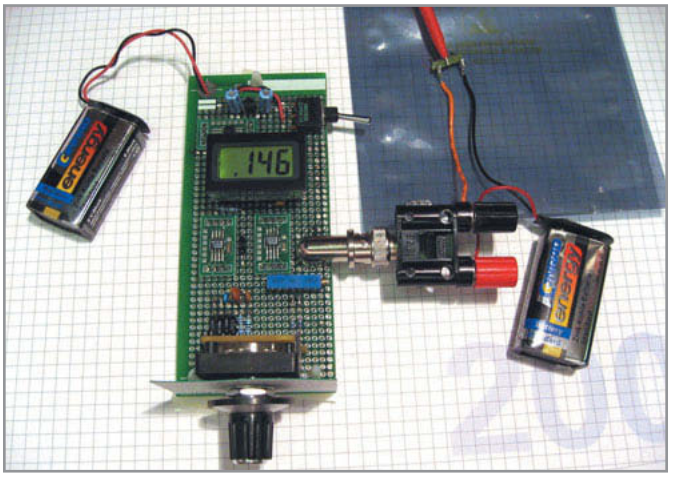

Photo 3—This is the setup I used for surface resistance measurements. A second 9-V battery is used to build an ohmmeter, and the test probe is made with a 1-cm-wide header and two test pins.

gigaohms, but this is not a surprise. Even good antistatic bags are specified for typical surface resistance of 10-GΩ per square. In fact, such bags have an inner layer with a far better conductivity, but this layer is wrapped between two polymeric plastic layers that have a far higher resistance, just low enough to dissipate ESD charges.

Material	Measured current	Equivalent resistance (between two electrodes 1 cm apart)
Classic plastic bag	Less than 10 pA	Greater than 900 GΩ
FR4 Epoxy substrate	Less than 10 pA	Greater than 900 GΩ
Antistatic foam (pink)	17 pA	530 GΩ
Antistatic bubble wrap (pink)	42 pA	210 GΩ
Dry paper	70 pA	130 GΩ
Antistatic bag (black)	250 pA	36 GΩ
Antistatic carpet	11 nA	820 MΩ

Table 1—Here I list the surface resistivity of different materials, as measured with a 9-V battery and two electrodes 1 cm from each other.

So here we are. Was this journey into the world of low currents pleasant? I hope you are convinced that such a picoammeter should be on your workbench, especially because you can build one in a couple of hours. And, of course, I hope that you now have one more set of tools in your engineering toolbox: transimpedance amplifiers.

Robert Lacoste lives near Paris, France. He has 20 years of experience working on embedded systems, analog designs, and wireless telecommunications. He has won prizes in more than 15 international design contests. In 2003, Robert started a consulting company, ALCIOM, to share his passion for innovative mixed-signal designs. You can reach him at rlacoste@alciom.com. Don't forget to write "Darker Side" in the subject line to bypass his spam filters.

PROJECT FILES

To download VSM project files, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2010/237.

RESOURCES

Keithley Instruments, "Low Current Measurements," Application Note 100, www.keithley.com/data?asset=6169.

M. Pachchigar, "Design Considerations for a Transimpedance Amplifier," National Semiconductor, AN-1803, 2008, www.national.com/nationaledge/files/national_AN-1803.pdf.

B. Pease, "What's All This Transimpedance Amplifier Stuff, Anyhow (Part 1)?," *Electronic Design*, 2001, http://electronicdesign.com/Articles/Index.cfm?ArticleID=4346&pg=1.

SOURCES

AD8638 Auto-zero operational-amp
Analog Devices | www.analog.com

VSM Mixed-signal simulator
Labcenter Electronics | www.labcenter.co.uk

SP 200 3½ Digit voltmeter
Lascar Electronics | www.lascarelectronics.com

BAS416 Diode
NXP Semiconductors | www.nxp.com

IVC102 Amplifier and TLE2425 virtual ground
Texas Instruments | www.ti.com

NEED-TO-KNOW INFO

Knowledge is power. In the computer applications industry, informed engineers and programmers don't just survive, they *thrive* and *excel*.

For more need-to-know information about topics covered in Robert Lacoste's Issue 237 article, the *Circuit Cellar* editorial staff recommends the following content:

—

Radiation Detection
Digital and Analog Pulse Measurement
by Pete McCollum
***Circuit Cellar* 220, 2008**
Build a data acquisition system to measure cosmic rays, natural background radiation, and emissions from radioactive objects. Topics: Radiation, Geiger-Muller Tube, PGA, Parallel Processing

Go to: www.circuitcellar.com/magazine/220.html

—

Energy and Load Analyzer
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***Circuit Cellar* 202, 2007**
This datalogger can measure RMS voltage, current, power, harmonics, and frequency. You can analyze electrical values over time. Topics: Datalogger, Current, Harmonics, Frequency, FFT

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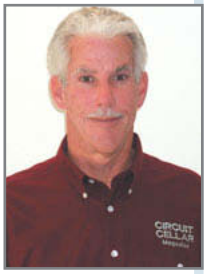

Wizard Lizard

Start Working with a Multidimensional SBC

Small SBCs are a dime a dozen, so what sets one apart from another? Sure, the hardware capabilities are important, but most SBCs cover the basics. However, there's more to the story than the spec sheet. Check out the Chameleon, a colorful controller that proves two heads are better than one.

Somewhere in my garage is a box with my first SBC, a circa-1970s '8085 "3-chip" board. It was a demo kit Intel came up with to pitch their 8085 MPU and its companion integrated memory chips—the 8155 (RAM + I/O) and 8755 (EPROM + I/O). Together they comprised a decently competent controller with enough memory and I/O to handle a simple embedded application. The "3-chip" demo even came with a tiny BASIC interpreter crammed into the 8755's 2-KB EPROM. Dr. Li-Chen Wang's article "Palo Alto Tiny Basic" is an interesting story in its own right that debuted in the very first issue of *Dr. Dobbs* (May 1976). Subsequently, his Basic found its way into the RadioShack TRS-80.[1]

What's surprising is how little things have really changed. It's still true you can do useful and fun things with just a few pages of code and some simple I/O (e.g., SIO, PIO, and

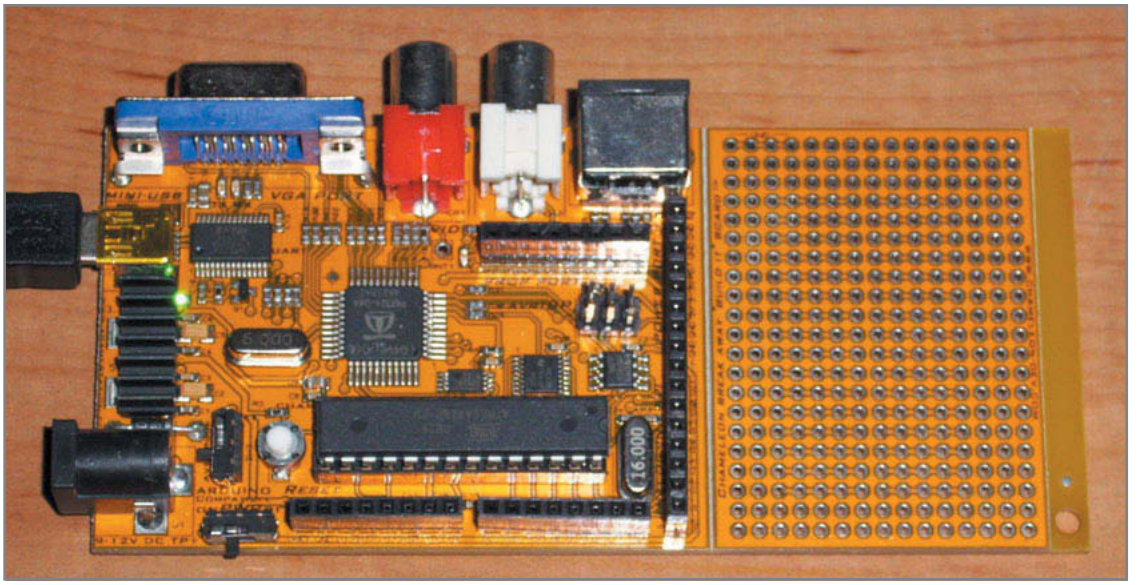

Photo 1—It's multicore and heterogeneous multiprocessing for the masses! Putting aside all the techno-babble, Chameleon makes it easy to do some pretty hard things like audio and video.

ADC). The success to this very day of SBCs like the Parallax BASIC Stamp was foreshadowed in that 8085 3-chip "BASIC Postcard."

But time (and silicon) marches on. This month, let's take a look at an SBC that does things that the old-timey 3-chip lash-up could only dream of.

TRIPLE THREAT

The Chameleon (see Photo 1) is the latest brainstorm from Andre LaMothe of Nurve Networks. It's an SBC with a lot of personality—make that "personalities" because it leverages unique I/O with the ability to host three completely different software regimes.

As you can see, the secret to the Chameleon's versatility is that it combines two MCUs, an Atmel AVR and a Parallax Propeller. (Note: a version with a Microchip PIC instead of the AVR is also available.) Along with the pair of MCUs, there's an FTDI chip for USB host PC connection, 1 MB of SPI flash for general-purpose data storage, and 64 KB of EEPROM for booting the Propeller. That's twice the EEPROM the Propeller needs, so the extra 32 KB is available for your application.

The AVR '328P integrates 32 KB of flash, 2 KB of SRAM, and 1 KB of EEPROM along with a decent (considering the limited pin count) complement of blue-collar I/O (SIO, PIO, and A/D). Meanwhile, inside the Propeller, you'll find eight (count 'em) 32-bit 20-MIPS cores, each with 2 KB of local RAM and shared access to centralized RAM (32 KB) and the chip's pins.

Neither of these chips is new to the pages of *Circuit Cellar* or Silicon Update readers. I've covered the AVR since the very beginning (e.g., "Not Your AVRage MCU," *Circuit Cellar* 81, 1997) as it's made good on the seemingly improbable proposition of introducing a new 8-bit architecture decades after the fact. Now the AVR is a top contender and Atmel offers a vast stable of parts covering the spectrum from "Pico" to "Mega."

More recently, I covered the Parallax Propeller ("Turning the Core-ner," *Circuit Cellar* 193, 2006), a truly innovative chip that brings esoteric computing concepts down to earth. The Propeller is a multicore chip that doesn't cost an arm and a leg, and it doesn't mind getting its hands dirty. As well, I covered Hydra, LaMothe's original Propeller-based SBC, in my article, "Game On" (*Circuit Cellar* 206, 2007).

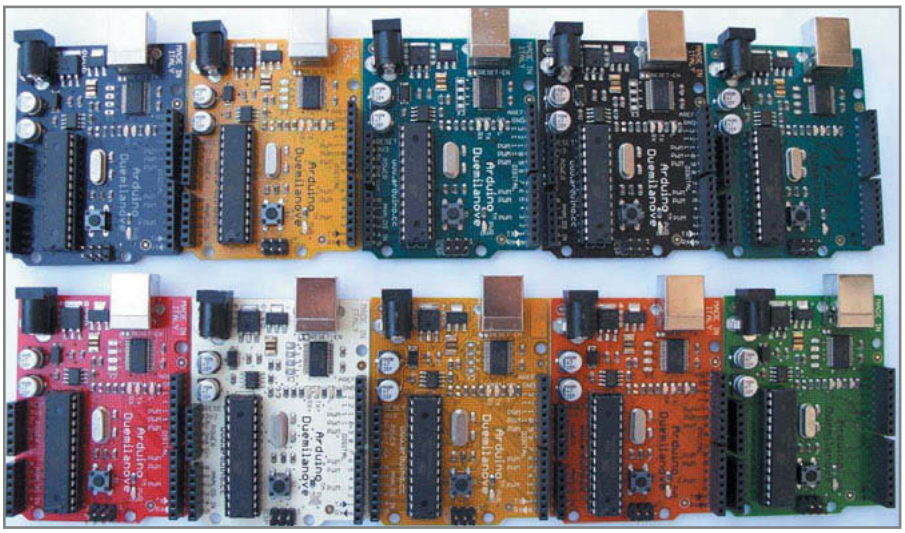

Photo 2—Arduino SBCs have struck a chord with a new generation of users by combining simple, low-cost SBCs with easier-to-use software tools.

Thus, two of the three aforementioned Chameleon software development options are self-apparent—namely, the standard AVR and Propeller toolchains. Look closely at the board and you'll see it includes the standard debug pod connector for the AVR. That means you can use any standard AVR toolchain, a likely option being Atmel's own immensely popular (being free helps) GNU-based AVRStudio.

The Propeller handles debugging via the USB port, so you don't even need a debug pod to use the Parallax tool based on a language they created called SPIN. While no language can make hard problems easy, you can take advantage of a growing library of pre-crafted "objects" Parallax maintains. It's quite easy to port existing Propeller code written for the Parallax and Hydra SBCs to Chameleon, with only minor changes to initialization code and pin assignment.

For your convenience, the Chameleon DVD includes both AVRStudio and the Propeller toolchain. Of course, DVDs can get stale, so you should check the Atmel and Parallax websites for the latest versions (or go ahead and install the DVD versions and then update).

However, you don't need these tools to get started. Indeed, you may never need them at all thanks to the third tool option. Say hello to Arduino.

R-WHO?

Most folks have probably heard mention of "Arduino" by now. I just Googled it and got 775,000 hits—and more than a few of them dealt with just how you pronounce the name. I say "R-DWEE-NO." But for a little more international flair, you might try "R-DO-WEE-NO," trilling the "R" for extra credit. Now that you've got that, let's try the latest Arduino board, the Duemilanove (2009). Altogether, class, repeat after me: "R-DO-WEE-NO-DO-EH-MEEL-AH-NO-VEH." On second thought, you're probably better off heading over to the Arduino website (www.arduino.cc) and listening to the official pronunciation (http://arduino.cc/en/uploads/Main/Arduino_Duemilanove.wav).

Now that you know how to pronounce "Arduino," look to the website's homepage to find out what it is: "Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and

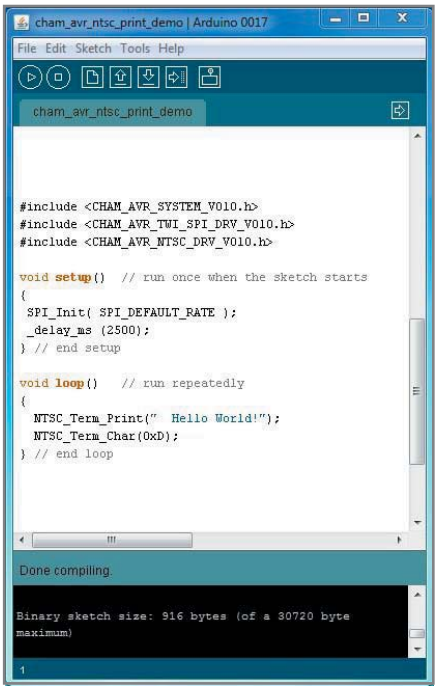

Photo 3—The Arduino GUI is about as simple as it gets. Although it uses the same GNU compiler technology as industrial-strength tools, the complexity is hidden behind a simple façade with none of the bloat and clutter of a traditional IDE.

software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments."[2]

It's natural to focus on the hardware, but the story goes way beyond the Arduino boards themselves (see Photo 2). Frankly, there's practically nothing to them beyond an AVR MCU and some connectors. Rather, what sets Arduino apart is a combination of openness, community, and easy-to-use software.

Arduino is said to be an "open-hardware" project, although your Google search will also turn up plenty of debate over exactly what "open" means. License fine print aside, it's clear there's a vibrant ecosystem of users and third-party suppliers who have latched on to the Arduino bandwagon.

And a big reason for the popularity is Arduino's simplified toolchain. Under the hood are the familiar GNU C/C++ tools, but Arduino hides them behind a simplified GUI stripped of bloaty features that might be unnecessary and confusing for beginners—which means pretty much everything (i.e., there's no debugger and all the arcane minutiae that go with it). What you see in Photo 3 is what you get; but for a simple app, it's all that you need. At least there's a built-in terminal emulator so you can PRINTF to your PC via the USB connection.

Indeed, even the term "toolchain" is overkill, because in the case of Arduino, it pretty much just has one link, the GUI. The difference is apparent right from the start. There's none of the complicated installation and configuration associated with industrial-strength tools. Just copy ARDUINO.EXE and install the FTDI virtual COM port driver (Windows did that automatically for me) and you're done. Another big plus is that the Arduino GUI is portable and works exactly the same on Windows, Linux, and Macs, which is something that can't be said for most tools.

Arduino reminds me of ARM's "mbed," which I covered a few issues back in an article titled "Easy (E)mbed" (*Circuit Cellar* 227, 2009). While the implementations are quite different ("mbed" being web-based), both share a philosophy of simplicity, ease of use, and community, aspiring to make the march of silicon accessible to all.

With the combination of AVR and Propeller, Chameleon delivers a lot of I/O capability for such a small board, not to mention one that costs just $59. Refer back to Photo 1 to see the connections as I go through the list. Along the bottom and right edge of the board are connectors that comprise signals the AVR contributes to the I/O mix. Most of these connect directly to the MCU, the notable exception being two spare SPI select signals conveniently located near the prototyping area. In the interest of compatibility, the signal names and layout take their lead from the Arduino standard. However, the Chameleon form factor isn't exactly the same, so you won't be able to plug in existing "shields" (Arduino-speak for piggyback I/O boards) directly, although it would be easy enough to wire a connection. At the top edge of the board are the Propeller media I/O features that set Chameleon apart, including (from left to right) VGA, NTSC, audio, and keyboard/mouse. In addition, there are 8 bits of extra Propeller I/O brought to a header for easy access.

Chameleon supports various prototyping options with a break-off breadboard area. The kit comes with a small test strip that you can double-side tape to the board for solderless experimentation. Or you can leave off the test strip and solder parts directly to the board for a more robust solution. Or, if you really don't need the extra space, just snap it off.

YOU TALKING TO ME?

Now that we've seen the pieces of the Chameleon puzzle (i.e., AVR, Propeller, and Arduino), let's put them together. Keep in mind this discussion applies to the "out-of-the box" configuration. Anyone willing to get their hands dirty can use the native tools (e.g., AVRStudio and Parallax SPIN) to give Chameleon a brain transplant. But for now, let's keep it simple.

At power-up (via the USB port or 9-V battery/wall wart), the AVR is in charge, running the Arduino (i.e., "C") application that resides in its

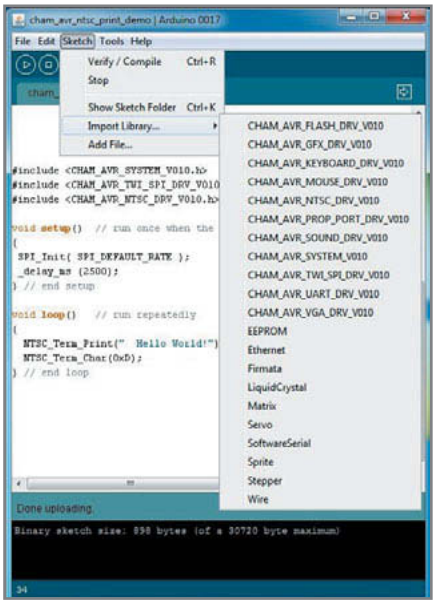

Photo 4—Programming Arduino "sketches" is easy thanks to a built-in library of useful functions, all the more so when enhanced with the Chameleon additions.

32-KB on-chip flash memory. That's not a lot of room; but as you'll see, it can go a pretty long way with a little help from its friend, the Propeller. Data size is limited, as well, to the 2 KB of AVR on-chip SRAM, but that's enough for simple apps. And don't forget the 1-MB SPI flash chip. You can drive it with software to store low-frequency or read-only data (e.g., constants, strings, look-up-tables, calibration factors, etc.). Ditto for the AVR on-chip 1-KB EEPROM.

Meanwhile, the Propeller powers up and loads itself with the library of predefined services (stored in the 64-KB EEPROM chip), and then waits for a command from the AVR. The AVR and Propeller communicate via the SPI port, and the protocol relies on fixed-length (3-byte) command/data packets. When the AVR issues a command, the Propeller dissects it and then passes it along to the core that handles the requested function.

One challenge for any multiprocessing scheme is making sure the overhead of interprocessor communication doesn't outweigh the gains. For instance, there is a command that allows the AVR to indirectly access the aforementioned Propeller 8-bit local port. It's fine for lights and switches; but needless to say, it's rather pokey considering the overhead of sending multi-byte packets between the AVR and Propeller just to twiddle a single bit.

Multiprocessing works best when it just requires a little communication to trigger a lot of local processing. And that's just the way it works with the "media" functions (i.e., audio and video) the Propeller handles. At the cost of shipping just a few bytes of command information, the AVR can have the Propeller streaming megabits of colorful graphics and polyphonic audio. The combination of AVR brains and Propeller brawn proves surprisingly capable in practice when each chip does what it does best.

Photo 5—I'm working, Steve, really. The "Crate-It" demo is a retro video game that puts the GFX "tile engine" through its paces."

LIBRARY CARD

An Arduino "sketch" (Arduino-speak for the "C" program running on the AVR) always has two sections: "setup," which is run once at start-up, and then the "loop," which runs forever. At a minimum, the "setup" for a sketch running on Chameleon needs to initialize the SPI connection to the Propeller and then delay a moment to give the Propeller time to boot up. I mention this because the out-of-the-box demos impose a 2.5-s delay, which seems excessive and gets old really quick (i.e., every time you edit/download). The documentation mentions this delay can be reduced or eliminated depending on what else your sketch is doing. I cut it back to 0.5 s without any problems, but left it 2.5 s in the examples.

Connecting your sketch to the Propeller "objects" (i.e., I/O drivers) is easy. All you do is copy the Propeller library files from the Chameleon disc to the existing Arduino library and, voila, everything is there for you to use (see Photo 4).

While most of the Chameleon library additions deal with the Propeller, some don't. For example, the SPI/TWI and UART modules simply run on the AVR and access only its hardware. In some cases the Chameleon service is similar to or overlaps that of the existing Arduino library, so you can stick with the latter if, for example, you're porting an existing Arduino sketch to Chameleon.

"Hello World" brings the Propeller into the equation, taking advantage of the chip's unique ability to drive NTSC and VGA video. The Chameleon API is a mini-me terminal emulator that has commands to clear the screen, move the cursor, and display a character or string. The only thing the AVR has to deal with is ASCII characters while the Propeller does all the bitmap font (8 × 8) and display machinations (e.g., scrolling) behind the scenes.

The "GFX" graphics library takes video to the next level (see Photo 5). It features a "tile engine" that treats the screen as an array of 32 × 24 tiles, each 8 × 8 pixels (i.e., 256 × 192 resolution), optionally mapped onto a larger "virtual playfield." For instance, you could specify a "playfield" of 64 × 48 tiles and then it's easy to scroll/flip between screens by just changing the start address. Do be warned: this "tile engine" is pretty complicated stuff unless you happen to be an old-school (à la 1980s video games) graphics guru. Also, due to the extra horsepower and frame buffer memory required for graphics, GFX only works with the NTSC screen option and not for VGA.

The Sound library mixes up to four notes (i.e., polyphonic) onto the

Photo 6—Hear that siren? With 180 MIPS under the hood, be careful you don't get pulled over for speeding.

mono RCA jack. A sound is specified in terms of frequency (0 to 2,000 Hz) and relative volume (0 to 255) and each channel can be stopped, started, or changed independently. The screenshot in Photo 6 shows how easy it is to add some spiffy sound effects to your Arduino sketches.

Keyboard and mouse functions may seem mundane, but if you've ever dealt with them you know there's a lot of wrestling with initialization, multi-byte packets, make-and-break scan codes, motion counters, and the like. The Chameleon library hides all the details behind high-level functions so you can easily capture a key press or track mouse motion and button presses. Just remember the Chameleon has only one PS/2 connector, so you can use a mouse or keyboard, but not both at the same time.

AS YOU LIKE IT

Chameleon does a good job of enhancing the Arduino concept with some unique I/O capabilities while remaining true to the keep-it-simple concept. Right out of the box, it only takes a few lines of code to create Arduino sketches that feature sound and video.

But nothing is set in stone. The documentation explains how to put together your own collection of different Propeller objects. You can write them yourself (or, better yet, choose from the free object database Parallax maintains) to create your own application-specific accelerators that take advantage of the Propeller's raw performance. Offloading the details to the Propeller is a win-win situation, making simple Arduino sketches shorter and easier, while at the same time freeing up AVR MIPS and flash to support more elaborate ones. Indeed, if you'll pardon the metaphor mix, one can imagine Chameleons with completely different spots (i.e., Propeller hardware, software, and API optimized for a specific application).

Kudos to LaMothe for putting together a complete package. To give you an idea, the "user manual" is 268 pages long! Going beyond just "what," it conveys valuable insight by explaining "how" and "why." In addition to all the tools involved (i.e., Arduino, AVR, and Propeller), the DVD is crammed with extras, including a compendium of related application notes, handy utilities, and even a BASIC compiler.

With something for Arduino-ites, Propeller heads, and AVR freaks, Chameleon lives up to its name by being able to change its appearance at will. It's got something for everyone and everything for someone—and maybe that someone is you.

Tom Cantrell has been working on chip, board, and systems design and marketing for several years. You may reach him by e-mail at tom.cantrell@circuitcellar.com.

REFERENCES

[1] TRS-80.org, "Dr. Dobb's Journal," www.trs-80.org/dr-dobbs-journal/.

[2] Arduino homepage, www.arduino.cc.

SOURCES

Arduino single-board computer
Arduino | www.arduino.cc

AVR MCU and AVRStudio
Atmel Corp. | www.atmel.com

Chameleon single-board computer
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Tom turned to game expert André LaMothe to see how to teach new-school hardware some old-school programming tricks. Are you game? Topics: Multi-core, Propeller, Hydra, Game Programming

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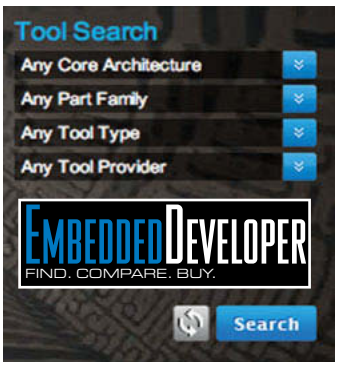

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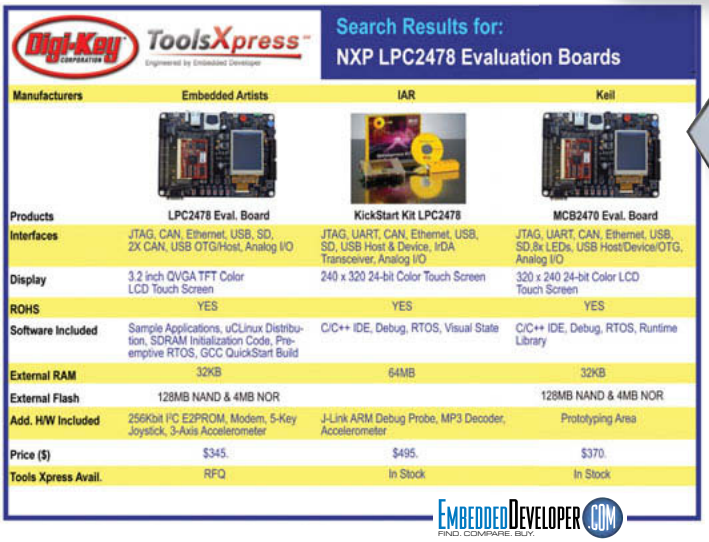
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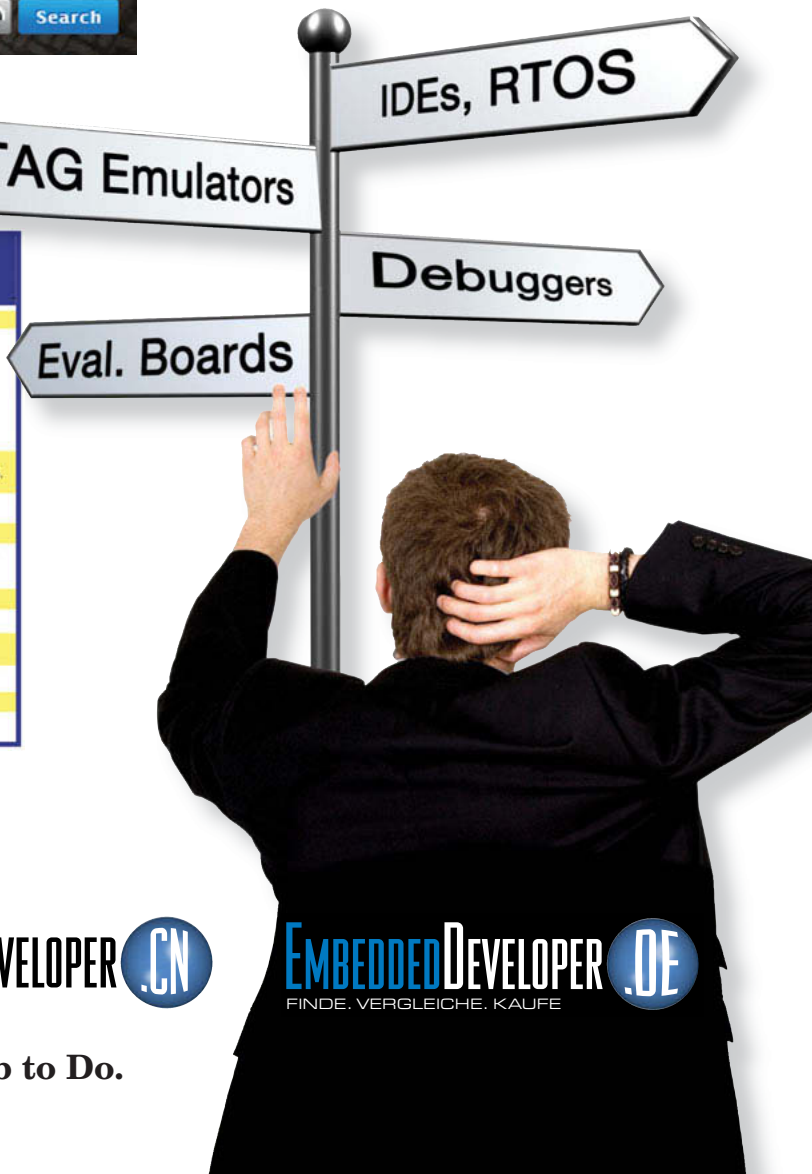

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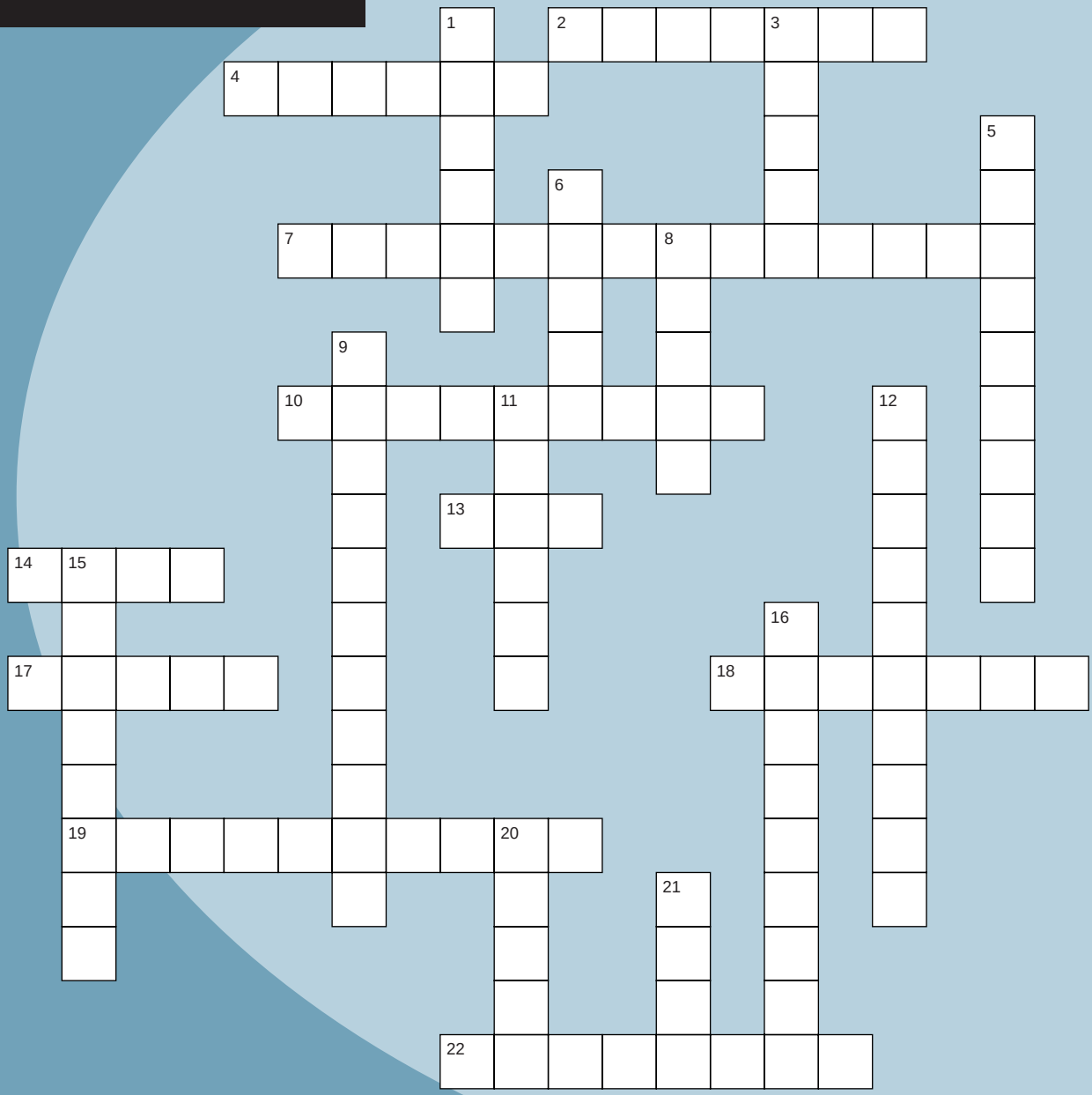

Down

1. A common's path
3. Quick surge of volts
5. Cu, Ag, Au
6. Extension .BAT
8. For placing orders online
9. 100 to 400 nm
11. Needs a server's services
12. Product info document [two words]
15. Set of size 0 [two words]
16. Reduce by 1
20. Conducts one way
21. NIST radio station

Across

2. He built a picoammeter for #237
4. Used in to find user info in Unix
7. \r [two words]
10. Depicts decisions, particularly software-related decisions [two words]
13. Phil Katz
14. 1 million
17. Trick a system
18. Customized
19. Translated by a compiler into machine language [two words]
22. 1,000 GB

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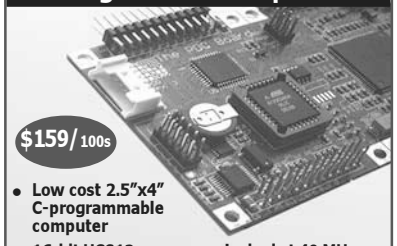

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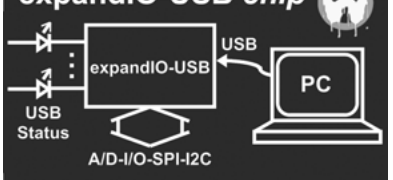

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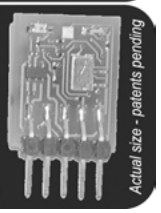

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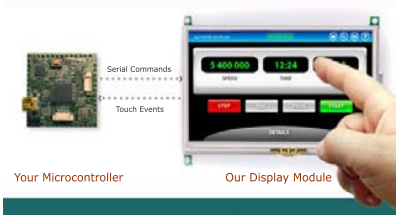

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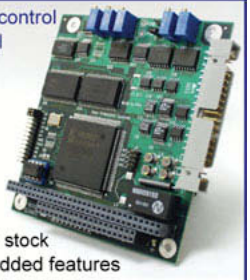

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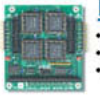

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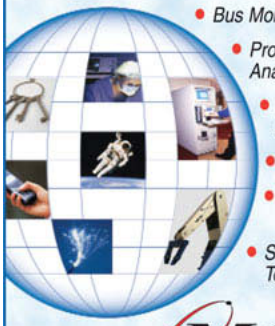

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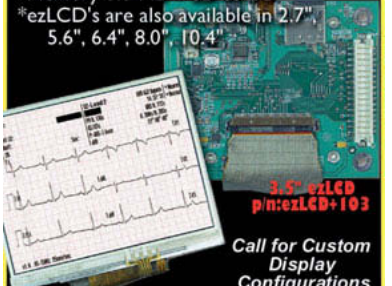

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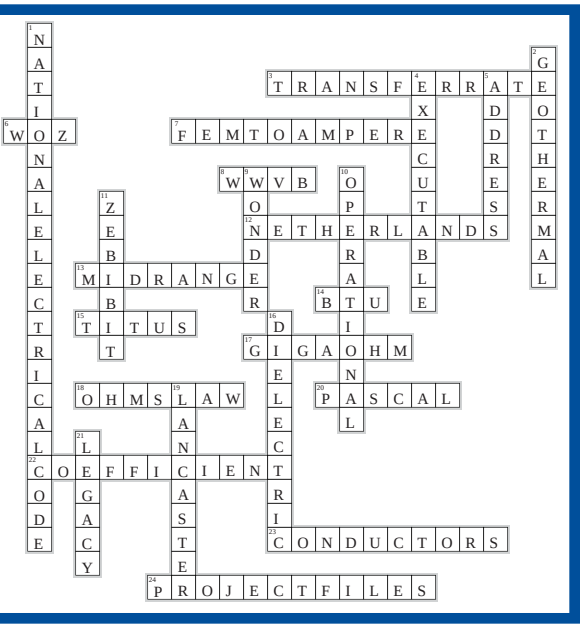
CROSSWORD ANSWERS from Issue 236

Across

3. **TRANSFERRATE**—The "10" in 10BaseT [two words]
6. **WOZ**—Wozniak
7. **FEMTOAMPERE**—10^{-15} amp; fA
8. **WWVB**—NIST radio station
12. **NETHERLANDS**—.nl
13. **MIDRANGE**—(Max + Min)/2
14. **BTU**—1,055 J
15. **TITUS**—Mark-8 minicomputer ; Virginia Tech, 1973
17. **GIGAOHM**—G ohm sign
18. **OHMSLAW**—V = R x I [two words)
20. **PASCAL**—Pa
22. **COEFFICIENT**—What is "-3" in the term $-3x^3y$?
23. **CONDUCTORS**—Silver, graphite, copper
24. **PROJECTFILES**—ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2010/236 [two words]

Down

1. **NATIONALELECTRICALCODE**—An electrician's "bible" [three words]
2. **GEOTHERMAL**—Energy in the Earth's crust
4. **EXECUTABLE**—EXE
5. **ADDRESS**—Leetspeak: *addy*
9. **WONDER**—1-d-r
10. **OPERATIONAL**—Op
11. **ZEBIBIT**—2^{70}
16. **DIELECTRIC**—An insulator
19. **LANCASTER**—*The TV Cheap Video Cookbook*, 1978
21. **LEGACY**—Old hardware in a new design



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PRIORITY INTERRUPT

by Steve Ciarcia, Founder and Editorial Director

Drive-by-Wire Roulette

If you drive a late-model car these days, it is probably "drive-by-wire." What this means is that there is no cable linkage between the accelerator pedal and the carburetor or fuel injection system, no unassisted fluid mechanics connecting the brake pedal directly to the master cylinder, and no mechanical linkage between the shift lever and the automatic transmission. Instead, there are sensors under the pedals and switches under the shift lever that transmit force and position information to an on-board computer that coordinates all this to physically control the real brakes, real motor, and real vehicle. Step on the brake or shift into drive and pray that the guy who wrote the software was an MIT grad.

As I'm writing this, all the insanity about floor mats under the accelerator, adding shims or whatever to sticky pedals, and about a hundred other car problems is still going on. For Toyota, it has become the problem of the day and then the fix of the week. While nothing has been entirely solved as of yet, I was glad someone in the press finally asked whether all the electronics in cars could be causing some of these problems. That question made me smile, perhaps because I'm an electrical engineer and I know that "secure electronic control" is an oxymoron. Engineers only design perfect circuits and write perfect code, of course, so it has to be the floor mats and stupid drivers. ;-)

I started thinking about all the rest of the electronics I depend on like my router, webcams, home control system, etc.—and my experience with them. Anyone who thinks that electronic stuff works right all the time is nuts!

When I spend a few months at the cottage, I depend on all the electronics at home to keep running smoothly. My experience is that if the device can be even remotely described as "electronic," it will hang up, screw up, or bite the dust at some point in that few months. It might be EMI from a lightning strike, transient spikes on the power line, or incongruous inputs causing just plain gotchas in my control software, but it does happen. The typical failures I experience with commercial electronics aren't just dead failures. More often than not, they just stall or get stuck in some aberrant operating pattern. It seems stupid that modern commercial hardware doesn't seem to know it isn't working properly and reset itself, but it doesn't. Rather than wait three months to clear a stuck router or video server, I chose to rely on tried and true brute force. I use a bunch of electromechanical timers on the power lines to turn the devices on/off/on once every 24 hours. It doesn't keep a web camera from hanging after the thunderstorm today, but it usually fixes it for tomorrow.

I speak from experience on this subject. One poignant example was many years ago when *Circuit Cellar* columnist Jeff Bachiochi and I designed an electromagnetic bug-repelling device for a customer (who subsequently sold a million of them on The Home Shopping Network). To make a long story short, it used a single-chip microprocessor to pulse an electromagnetic coil. As you might expect, when manufacturing a high-volume device, cost goals determine the trade-off between satisfactory operation and bullet-proof safety. For example, we could use thinner wire and cheaper plastic bobbins because the coil only experienced 5% duty cycle and rarely got hot. Fortunately, just as we were about to send the design out for production, we experienced a transient on the test bench that locked the processor into a 100% duty cycle on the 120-VAC coil. I can't remember which of us got to the fire extinguisher first, but it was quick.

The reality was that we had designed a device that satisfied the customer's specification, but we hadn't thought far enough to make sure what happens (or doesn't happen) when it only meets those specs. Fortunately for us, the microprocessor we used had a watchdog timer on it so a quick code change eliminated the chances of 100% duty cycle for more than a few tens of milliseconds.

Cars with dozens of networked processors are a bit more complicated and I'm glad I'm not the one responsible for making this mess work correctly. Given all the sensor, switch, and electromagnetic device coordination, I can't help but feel that somewhere in a million lines of control code the likelihood that someone missed a biggie or two is better than even money. Hence, 100% gas pedal duty cycle!

The irony of all this is that car electronics is extremely sophisticated and drive-by-wire cars that are computer-controlled to go should just as easily be computer-controlled to stop. Just like my cheap plastic bobbin that depended on having less than 20% duty cycle to stay safe, many American and Japanese car manufacturers simply depend upon having brakes that can out-power the motor and stop a runaway car rather than using more sophisticated (costly?) options. German cars, like BMW, simply have a couple more sensors and software that inhibits conflicting control inputs, albeit a rusty gas pedal or a misplaced floor mat. If you step on the gas and brake at the same time, German cars say verboten and give priority to the brake.

In my opinion, successful embedded control design isn't always just about making something work correctly. Good designers take the effort to make sure it can't work any other way! Perhaps Toyota concluded that a $2 sensor on the brake or gas pedal was too much to add to millions of cars, but it sure seems that some simple code that said, "press the gas pedal or press the brake but not both (at greater than 30 mph)," might have solved some of these problems a long time ago. In the meantime, while they continue to figure it all out, I'll just go enjoy my BMW. Of course, such satisfaction only goes so far, since it is parked next to my Toyota. ;-)

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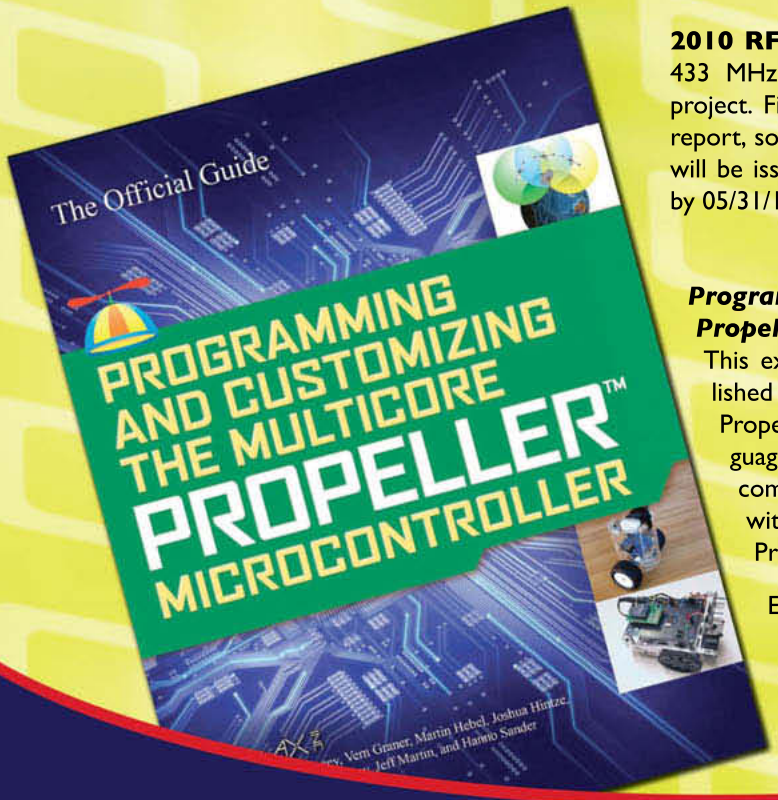

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BONUS ARTICLE

by Stefan Negru

The FeelTagged System

An Arduino-Based HCI Project

With Arduino board, some programming skills, and a little imagination, you can create some pretty futuristic HCI projects. This article covers how to communicate human emotions on a 2 × 16 LCD.

An Arduino board is a great prototyping platform. Its easy-to-use software and hardware make it ideal for rapidly developing new devices and methods for interacting with computers. With this in mind, I used an Arduino board in a research project concerned with finding new ways to facilitate interaction between humans and computers. My focus was on displaying, identifying, and expressing human feelings in a way that a machine could understand.

I built my own board for the project (see Photo 1). After a few iterations, I came up with a possible solution that featured the Arduino, a basic 2 × 16 alphanumeric LCD, several super-bright color LEDs (green, red, and blue), and several other components like resistors, transistors, and a potentiometer (see Figure 1). I used Twitter for communicating emotions. To make design user-friendly, I predefined a series of feelings—happy, sad, and angry—and then integrated them with messages to be displayed on the LCD along with different colored LED combinations.

A Python script on the host computer handles the USB communication with the Arduino device and Twitter API. I used two modules in the Python script: "pyserial" to facilitate the USB communication and "python-twitter" to work with Twitter. I used an HTML form for collecting user data. The form contain basic questions. Based on the answer, the script decides which feeling to display on the device. The Arduino also sends the displayed message to the host computer where it is forwarded to a Twitter account.

I initially used the potentiometer as a user input to set the intensity of the feelings. But due to some stability issues, I repurposed it for checking if the LEDs have the proper intensity.

The most time-consuming aspect of the project was disabling auto reset during USB communication with the device. The auto reset function is for uploading sketches to the board without having to press the Reset button. The serial DTR hardware control line controls this. It auto resets whenever the system is trying to open a serial connection (e.g., via the USB cable). In order to send and receive data from board, I had to keep the connection alive. After trying a software approach and several programming languages such as Java, PHP, and C#, I decided to use an "official" solution from the Arduino website. It

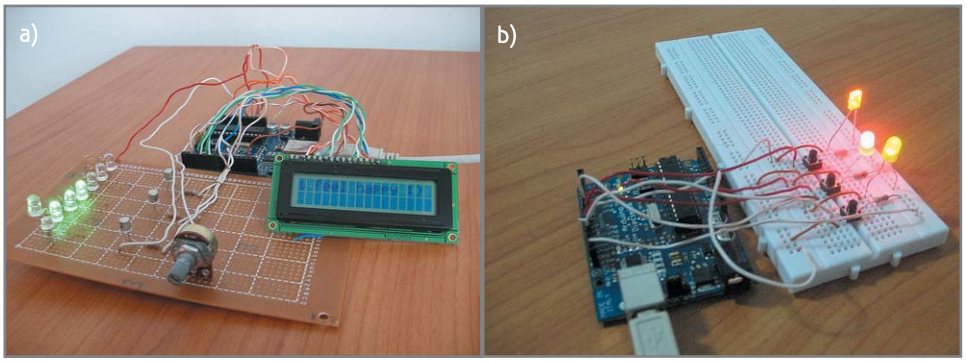

Photo 1a—I started with an simple representation of my idea and built a first prototype. I then began adding more elements, and after a few iterations, I ended up with my final prototype **(b)**.

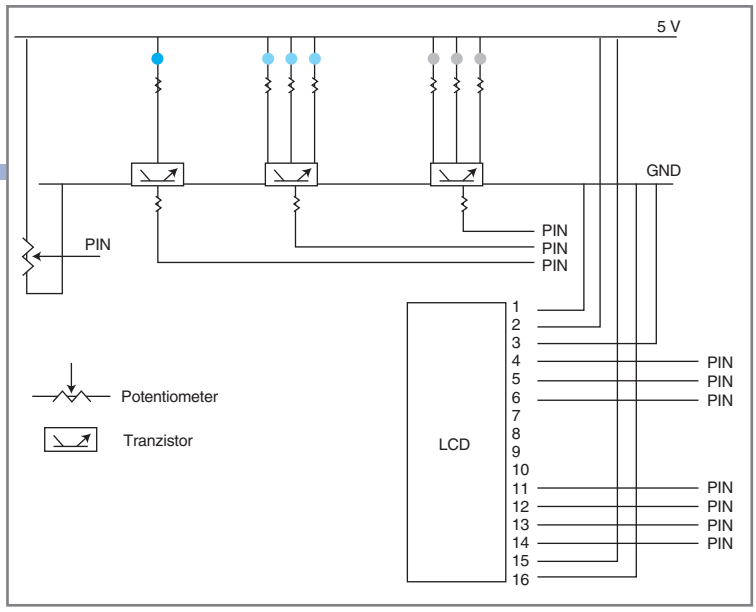

Figure 1—The wiring for the final "shield." I used three 2N2222 transistors, super-bright LEDs, a basic 2 x 16 character LCD, and a potentiometer.

suggested linking the 5-V pin and RESET pin with a 120-Ω resistor. This did have a drawback though. I have to remove the resistor when uploading a sketch to the device.

An alternative to USB communication would involve adding an Ethernet shield for a direct communication with Twitter and the computer. But that approach would come with an entirely new set of problems.

I plan to improve this project by adding several sensors so I can better identify and display feelings. I also plan to use the Emotion Markup Language (EmotionML 1.0, www.w3.org/TR/2009/WD-emotionml-20091029/)—which was designed to enable computers to represent and process data that reflects "affective" states—in a future version of this project.

Author's note: Source code is available at www.github.com/blankdots/Feeltagged. A video demonstrating the project is available at www.vimeo.com/4930674.

Stefan Negru is studying for an MSc in Software Engineering at The Faculty of Computer Science at The A. I. Cuza University of Iasi in Romania. He is focused on developing new and interactive applications. For more information about his work, go to www.blankdots.com.

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